FEASIBILITY OF AQUATIC PLANT HARVESTING IN WATER QUALITY AMELIORATION AND NUTRIENT MANAGEMENT IN A SHALLOW IMPOUNDMENT - THE ORANGEVILLE RESERVOIR

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EXECUTIVE SUMMARY

Aquatic plant harvesting potentially represents a simple and relatively low cost method of nutrient management. In situations where macrophyte biomass is high in relation to the total volume of water (e.g., in shallow ponds and impoundments), long-term harvesting, combined with control of nutrient sources, may remove a sufficient portion of nutrients to significantly improve water quality.

In most southern Ontario reservoirs, eutrophication has been reported as a major reservoir mangement problem. Many reservoirs experience high surface coverage by aquatic weeds. In a recent survey of 51 southern Ontario reservoirs, mechanical weed harvesting was found to be in use as a control measure in four, and under consideration in an additional five.

The Orangeville Reservoir, located at the headwater of the Credit River, is typical of many southern Ontario impoundments. The reservoir was created to control spring flooding and to provide summer low-flow dilution of effluent from the Orangeville sewage treatment plant (STP). The reservoir is shallow and supports heavy growth of aquatic macrophytes in summer throughout nearly all of its area. Aquatic plant harvesting was carried out in the reservoir to a limited extent in 1984 and 1985, and somewhat more extensively in 1986.

A study of the role of plant harvesting in the nutrient budget of the Orangeville Reservoir was undertaken in 1986. The objective of this study was to evaluate the potential of biomass harvesting as a water quality management tool for shallow reservoirs. This was accomplished through:

- a one-year evaluation of the nutrient budget for the reservoir;
- an evaluation of the role of aquatic sediments in the nutrient budget; and
- an evaluation of the effects of plant harvesting on water quality through comparison with historic data.

Of the nutrients entering the reservoir, it was found that 54% of total nitrogen and 52% of total phosphorus are retained, thereby reducing downstream export. Nutrients retained by the reservoir are removed either directly by sedimentation or through

bioconcentration by the aquatic plant community. Total nitrogen and phosphorus concentrations in the surficial sediments average 2.4% and 0.14%, respectively.

Bottom waters in the deepest part of the reservoir become intermittently depleted in oxygen, resulting in releases of phosphorus and nitrogen (probably as ammonia) from the sediments. The degree of oxygen depletion in bottom waters at the shallow depths (less than 3 m) typical of most of the reservoir, appears to be insufficient to result in substantial nutrient remobilization.

Harvested plant tissues contained an average of 1.58% nitrogen and 0.25% phosphorus on a dry weight basis. These concentrations are higher than threshold concentrations identified as indicating nutrient limitation. Thus, aquatic plant production is apparently not limited by nutrient availability.

The inventory of nitrogen in the plant community is close to the quantity annually retained by the reservoir, indicating that plants may be important in nitrogen removal. This is supported by the observation that bioavailable nitrate nitrogen is depleted in the water column during the growing season. Some of this accumulated nitrogen is released back to the water column during senescence and decay in late fall, winter and early spring.

The inventory of phosphorus in the plant community is about six times greater than the quantity of phosphorus retained by the reservoir, and exceeds the annual phosphorus supply to the reservoir by about three times. Thus, phosphorus requirements are met primarily by uptake from the surficial sediments. This is further supported by the lack of phosphorus depletion in the water column during the growing season.

Harvesting of 23.6 tonnes dry mass of plant tissue from the reservoir in 1986 resulted in no measurable effect on nutrient export from the reservoir to the Credit River. This biomass represents less than 5% of the total standing crop in the reservoir during the growing season.

The Orangeville Reservoir presently accounts for about 23% of the phosphorus loading and 22% of the total nitrogen loading to the upper Credit River, based on combined loadings from the reservoir and the Town of Orangeville STP. Removal of 200 tonnes of

biomass would be expected to reduce the downstream nitrogen export by an estimated 1 tonne per year. This rate of harvest would require a large increase in harvesting efficiency that may be impractical. Removal of 1 tonne per year of nitrogen from downstream export through a greatly increased harvesting effort would represent a reduction in the total (STP + reservoir) nitrogen loading of only 3%. Phosphorus export would be initially unaffected by an increase in plant harvest, since phosphorus uptake is from the sediment. An increase of four-fold or more in the harvest would result in a phosphorus deficit in the reservoir (removal would exceed supply). This should lead to a depletion in phosphorus concentrations in the surficial sediments that should result in the gradual oligotrophication of the reservoir. A more oligotrophic system should become more efficient in phosphorus removal and retention, thereby reducing downstream export.

Recent improvements in treatment efficiencies at the Orangeville STP have achieved reductions of 75% in phosphorus loadings and 50% in nitrogen loadings. This has resulted in a marked increase in the inorganic N/P ratio in total loadings to the upper Credit, implying a probable shift from nitrogen to phosphorus limitation in primary production. In a phosphorus-limited system, a limited reduction in nitrogen export due to plant harvesting would probably be ineffective in reducing primary production. An eventual decline in phosphorus export and reduction in eutrophication in the upper Credit might be achieved in a long-term harvest program that removes about 100 tonnes dry mass or more per year from the reservoir, although the expected rate and magnitude of this decline is unknown.

The feasibility of plant harvesting in controlling nutrient export from small reservoirs in southern Ontario depends on the relative significance of nutrient export in the overall nutrient budget of the downstream watershed. Reductions in sediment phosphorus concentrations may be achievable in long-term harvesting in reservoirs such as Orangeville. If phosphorus removal by harvesting exceeds phosphorus retention, gradual oligotrophication and an increase in phosphorus retention should result. Measurable decreases in nitrogen export may be achievable by plant harvesting, although the amount of harvesting required may necessitate a large effort.

1.0 INTRODUCTION

1.1 Background

Over the past ten years, major initiatives have been undertaken to reduce nutrient loading to the Great Lakes. However, recent reports from both the Pollution from Land Use Activities Reference Group (PLUARG) and the Great Lakes Water Quality Board indicate low cost, technologically simple measures such as phosphate reduction in household detergents and upgrading of municipal sewage treatment plants may not be sufficient to achieve the water quality objectives for the lower Great Lakes as stated in the 1972 agreement. In addition, multi-year studies show that loadings of inorganic nitrogen compounds to the lower Great Lakes basin are increasing (Taub, 1984).

Aquatic plant harvesting potentially represents a simple and relatively low cost method of nutrient management which has received little attention to date. Generally, nutrient loss due to plant removal is insignificant compared to the total nutrient budget in a waterbody. However, in some situations where macrophyte biomass is high in relation to the total volume of water (e.g., in shallow ponds and impoundments), long-term harvesting, combined with control of nutrient sources, may remove a sufficient portion of nutrients to significantly improve water quality.

During the 1950's and 1960's, numerous shallow reservoirs and ponds were created by dam construction in southern Ontario river systems to provide spring flood control and streamflow augmentation during summer low flows. A survey of such reservoirs being managed by conservation authorities was conducted by Credit Valley Conservation Authority (CVCA) during the fall of 1984. Fifty-one impoundments ranging from 3.6 to 2,000 hectares, were identified. The majority of the reservoirs surveyed are shallow (≤ 5 m deep) waterbodies. Over 80% of the survey respondents reported eutrophication as a major reservoir management problem. Many reported high surface coverage by aquatic weeds. Weed control methods are employed in 29 (58%) of the reservoirs. The most common control method is a combination of winter drawdown and chemical spraying. Mechanical weed harvesting is currently used in four of the reservoirs and is under consideration in an additional five reservoirs.

The Orangeville Reservoir, located northeast of Orangeville, Ontario at the headwater of the Credit River, is typical of many southern Ontario impoundments. The reservoir was first flooded in 1969 as a measure to control spring flooding and to provide summer low-flow dilution of effluent from the Orangeville sewage treatment plant (STP). The reservoir supports heavy growth of aquatic macrophytes (mainly Myriophyllum and Elodea) in summer throughout nearly all of its area.

CVCA, the agency responsible for management of the reservoir, purchased a mechanical plant harvester to remove plant biomass, thereby removing nitrogen and phosphorus from the reservoir and from export downstream to the Credit River. Plant harvesting also improves the recreational potential of the reservoir in summer.

Harvesting was first carried out, to a limited extent, in 1984. A total of 18.5 tonnes dry mass of plant matter were removed that year. Mechanical problems limited harvesting in 1985 to about 19 tonnes dry biomass. Harvesting carried out in 1986 is evaluated more extensively in this study.

The effectiveness of plant harvesting in controlling nutrient export from the Orangeville Reservoir was evaluated in a preliminary study by Clarke-Whistler et al. (1985). Results of this study were based on nutrient budgets determined from a very limited database on surface water hydrology and water quality in watersheds draining into the reservoir and thus, are subject to a considerable degree of uncertainty.

In this preliminary study, it was concluded that the reservoir acts as a net sink rather than a source for nitrogen and phosphorus in the watershed. Aquatic plants appeared to derive phosphorus primarily from the sediments and to return this phosphorus to the sediments following die-off and decay. However, plants appeared to take nitrogen primarily from the water column, and to return much of this nitrogen to the water column following die-off. Thus, it was concluded that plant harvesting could effectively reduce nitrogen loadings from the reservoir to the Credit River. Nitrogen control was of primary interest since it was felt that nitrogen rather than phosphorus may be the nutrient limiting primary productivity in the upper Credit River (MOE, 1981). This concern led to the incorporation of a denitrification plant in an expansion of the Orangeville STP (completed May 1985).

1.2 Objectives

A more intensive study of the role of plant harvesting in the nutrient budget of the Orangeville Reservoir was undertaken in 1986. The overall objective of this study was to evaluate the potential of biomass harvesting as a water quality management tool for shallow reservoirs from a site-specific standpoint. This was accomplished through:

- refinement of the nutrient budget for the reservoir through the collection of site-specific data on hydrology and water quality;
- evaluation of the role of aquatic sediments in the nutrient budget; and
- evaluation of the effects of plant harvesting on water quality through comparison with historic data collected prior to harvesting.

2.0 STUDY AREA

The Orangeville Reservoir is located on the northeast edge of the Town of Orangeville, at the headwaters of the Credit River. It forms a major part of the 344 ha Orangeville Reservoir Conservation Area, operated by the CVCA. In addition to the conservation area, landuse in the drainage basin consists primarily of agriculture (pasture, grain, hay and livestock) and woodlands.

The reservoir was first inundated in 1969. The flooded area was formerly a cedar swamp at the watershed divide of the Credit River (flowing into Lake Ontario) and the Nottawasaga River (flowing into Georgian Bay). Dykes at the north and south ends of the swamp contain the reservoir within the natural basin provided by the surrounding topography. Flow control and overflow structures are located at the south dyke to direct all outflow to the Credit River.

Orangeville Reservoir and the surrounding drainage basin are depicted in Figure 2.1. The total capacity of the reservoir is $3.08 \times 10^6 m^3$. A volume of $1.57 \times 10^6 m^3$ has typically been maintained for flow augmentation. Dam operation was orginally scheduled to achieve a minimum year-round flow of 0.28 m^3/s. However, the reservoir policy was modified in 1978 to facilitate water-based recreational activity and enhance waterfowl habitat. During the summer, the control valve has been generally kept closed to maintain high water levels. Under these conditions, flow to the Credit River occurs as seepage (about 0.014 to 0.057 m^3/s) through the dyke (IEC, 1981). During August through November, the valve is opened to allow higher flows for low flow augmentation. By the end of November, the reservoir is at its lowest level. It is maintained at this level through the winter to maximize storage capacity for the spring thaw (IEC, 1981). Since 1985, attempts have been made to maintain higher outflow rates in summer.

The reservoir is shallow, and the littoral zone supporting plant growth covers an estimated 95% of the surface area. The mean depth of the reservoir is about 1.5 m. The maximum depth is about 7.6 m, found in a small area of the east arm of the reservoir.

Three stream systems drain into the reservoir (Figure 2.1). The largest is Monora Creek, a permanent flowing stream draining the area to the west of the reservoir. The East Tributary is a small, permanantly flowing stream fed by a main south branch and a north

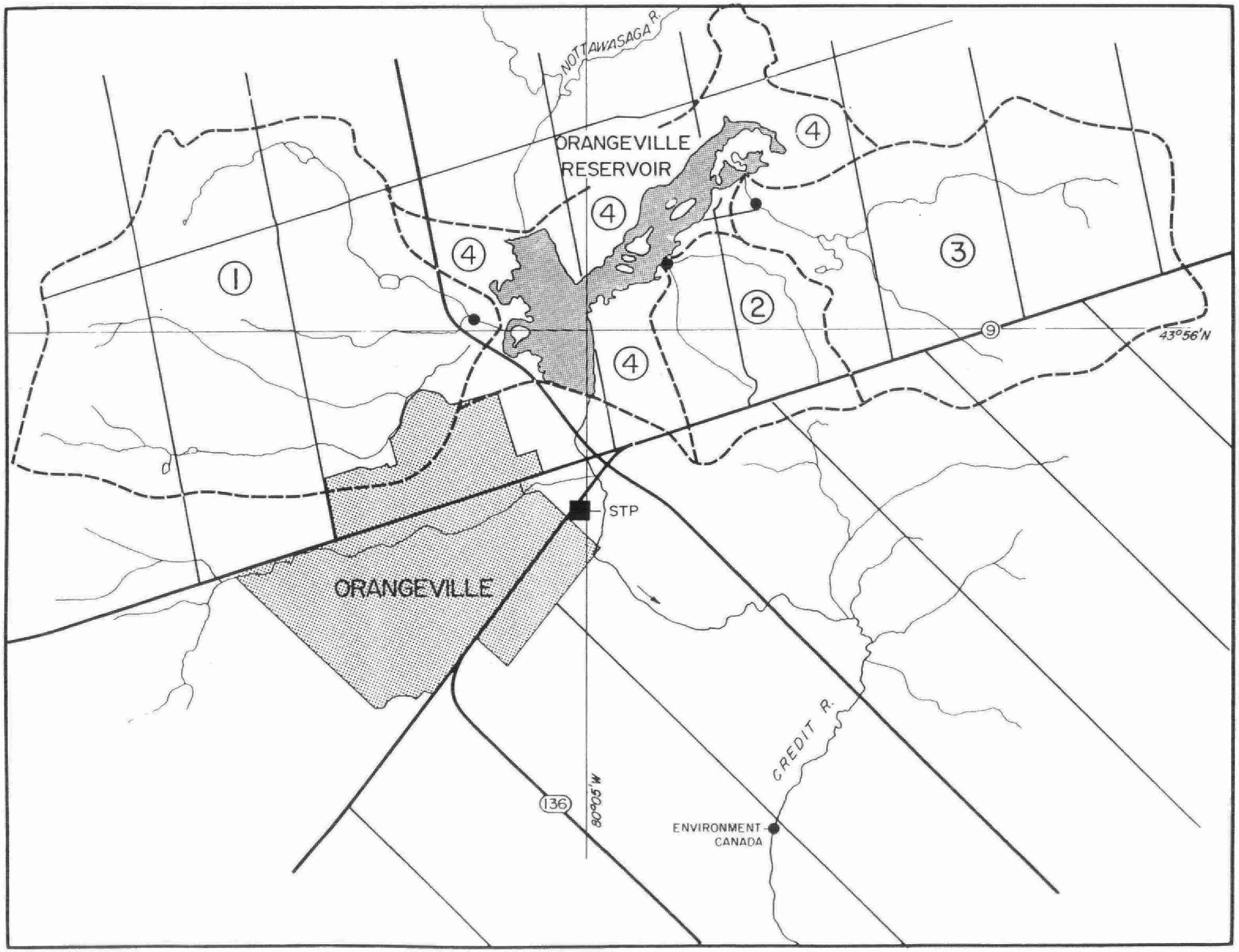


FIGURE 2.1
Orangeville Reservoir and Upper Credit River Watersheds

● STREAM GAUGE LOCATIONS

WATERSHED

1 MONORA CREEK

2 EAST TRIBUTARY

3 NORTH TRIBUTARY

4 ORANGEVILLE RESERVOIR

0 500 1000 2000 3000
SCALE METERS

N

branch which flows only during periods of peak runoff. The north and south branches of the East Tributary join about 100 m before emptying into the east arm of the reservoir. The North Tributary drains a larger area than does the East Tributary, but tends to have lower flows and to dry up during winter and periods of low precipitation. About 14% of the land area drained by the Orangeville Reservoir empties directly into the reservoir through surface runoff or small gullies. Also, a groundwater spring is known to have emptied into the reservoir area prior to impoundment, and probably continues to seep through the bottom of the reservoir. Orangeville Reservoir Drainage basin and watershed areas (km^2) are summarized as follows:

• Monora Creek	11.65
• East Tributary	2.68
• North Tributary	8.38
• Direct Runoff	4.06
• Reservoir Surface	1.75
TOTAL BASIN	28.52

3.0 MATERIALS AND METHODS

3.1 Hydrology

Surface water contributions to the reservoir were determined by measurement of streamflows in Monora Creek, the East Tributary and the North Tributary. Measurements of the reservoir outflow were also made.

Water levels (and streamflows) were measured continuously using a Stevens F-Type water level recorder during the ice-free season near the mouth of Monora Creek (Figure 3.1). In cold weather (January until early March, mid to late December), ice formation in the stilling well prevented continuous water level measurements. Under these conditions, water levels tended to be relatively low, and were recorded intermittently (usually weekly).

Water levels in the East Tributary were measured intermittently (usually weekly) from a vertical staff gauge installed near the stream mouth (Figure 3.1). Water levels were not measured on the North Tributary, but occassional discharge measurements were made to calibrate streamflow with flows in the East Tributary.

Stage height-discharge relationships were determined by making several measurements of streamflow in the two gauged tributaries, as detailed in the Environment Canada streamflow field manual (Terzi, n.d.). Totals of 16 and 6 measurements were made at Monora Creek and the East Tributary, respectively, using a vertical axis, Gurley No. 622 current meter.

A correction for the effects of ice on the stage-discharge relationships was made by measuring under-ice flows in Monora Creek on one occasion. Under-ice flows were about half of the flows found at the same stage height under ice-free conditions. The same ice correction factor was assumed to apply to East Tributary flows.

A beaver dam constructed downstream of the Monora Creek gauging station began to alter the stage-discharge relationship in the fall of 1986. A series of streamflow measurements were made during the fall to document and adjust for these alterations.

FIGURE 3.1: Upper Photo - MONORA CREEK STREAM GAUGE STATION. ARROW SHOWS WATER LEVEL RECORDER INSTALLATION
Lower Photo - EAST TRIBUTARY STREAM GAUGE STATION

Spot measurements of streamflow were made near the mouth of the North Tributary. Three measurements were made in the North Tributary under conditions that spanned a considerable range of streamflow conditions during the period of measureable flow. The North Tributary had negligible flow (judged to average about 0.001 m^3/s) until spring thaw in early March.

Conservation area personnel of CVCA maintain records of reservoir levels and weir and gate openings to measure discharge from the Orangeville Reservoir. Operating data from 1986 were used by CVCA hydrology staff to estimate discharges from the south control structure.

Precipitation data were used to calculate the quantity of water falling directly onto the reservoir surface. Monthly precipitation records for 1986 were obtained from the Atmospheric Environment Service, Environment Canada for AES "CLIMAT Station 50, Orangeville MOE".

As a check on the water balance, chloride loadings from inflowing streams and atmospheric deposition were compared with estimated chloride loadings to the Credit River from the south dam structure. Chloride behaves conservatively in the aquatic environment so that inputs and outputs from the reservoir should be roughly equal. A poor chloride balance indicates error in the calculated water balance, and the input-output ratio permits a calibration of the overall water budget.

3.2 Water Quality

Water samples for determination of nitrate, nitrite, total Kjeldahl nitrogen, total phosphorus and chloride were collected from the three tributary stream systems and from the reservoir outflow over the course of 1986. All inflowing stream samples were collected near the mouths of the watersheds at the stream gauge stations (Figure 2.1). Sampling frequency was approximately weighted according to the relative importance of each inflowing stream system in the water budget of the reservoir, and was increased during periods of high discharge. Forty samples were collected from Monora Creek, 21 from the East Tributary, and 16 from the North Tributary between January and December 1986. Samples from the outflow were collected approximately once weekly.

Water samples were also collected from a 3-m deep station in the lower portion of the reservoir about 300 m upstream from the south dyke (Station 1) and from a 6.0- to 6.5-m deep station in the area of the deep hole in the upper portion of the east arm (Station 2) on three occasions in the summer. These samples were collected to evaluate vertical nutrient profiles and possible nutrient release from the sediments. At each location, vertical temperature and dissolved oxygen profiles were taken. Water-column composite samples (surface to 1 m above bottom) were collected for nitrogen and phosphorus determinations. When vertical stratification was evident, samples were also collected at about 0.5 m above the bottom by Van Dorn.

All water samples collected from inflowing streams and from the Orangeville Reservoir were analyzed by Beak Consultants Limited. Chloride and nitrate were determined by ion chromatography. Nitrite, total Kjeldahl nitrogen and total phosphorus were determined according to "Standard Methods" (APHA, 1985). Dissolved phosphorus was not measured, since Clarke-Whistler et al. (1985) determined that this form showed little seasonal variation in concentration in the reservoir.

Outflow samples were analyzed by the MOE laboratories in Rexdale in their routine monitoring program for the Credit River. Two outflow samples were also analyzed by Beak Consultants Limited as an inter-laboratory check, and the agreement between the two laboratories was found to be good (Appendix 1).

3.3 Atmospheric Deposition

In addition to surface water sources, atmospheric deposition also contributes nutrients to the Orangeville Reservoir. Airborne phosphorus and nitrogen are deposited onto the reservoir surface in atmospheric precipitation, and also through dry deposition processes.

The Air Resources Branch monitors wet and dry deposition of several pollutants in the APIOS (Acidic Precipitation in Ontario Study) air quality and precipitation network. Although 1986 data are yet unavailable, the most recent published data (Tang et al., 1986) for 1983 should be reasonably representative of 1986 conditions (M. Lusis, Air Resources Branch, pers. comm.).

Annual wet deposition of phosphorus, nitrogen and chloride (mg/m^2) in the Orangeville area, based on deposition isopleths for 1983 (Tang et al., 1986), are as follows:

• $P\text{-}PO_4$	15
• N-TKN	500
• $N\text{-}NO_3$	480
• Cl^-	225

Dry deposition estimates of nitrate nitrogen given by Tang et al. (1986) are judged by those authors to be biased high, and are probably close to the rate of dry deposition of total atmospheric nitrogen. Dry deposition of nitrogen is about 300 mg/m^2 per year in the Orangeville area.

Dry deposition of phosphorus has not been measured in the APIOS network. A bulk (wet plus dry) annual deposition rate of 35 mg/m^2 for phosphorus has been identified for the Muskoka-Haliburton region (P. Dillon, pers. comm. cited by Clarke-Whistler et al., 1985), where wet deposition of phosphorus is in the range of 8 to 15 mg/m^2 (Tang et al., 1986). Thus, in Muskoka-Haliburton, bulk phosphorus deposition is about two to four times greater than wet deposition. Assuming this same ratio applies in the Orangeville area, a dry deposition rate of about 30 mg/m^2 is estimated for Orangeville.

Tang et al. (1986) report atmospheric chloride concentrations for Ontario, but did not estimate dry deposition rates. Dry deposition is calculated as the product of atmospheric concentations and the dry deposition velocity. Although deposition velocities for chloride have not been measured in Ontario, the range of values reported by Chan et al. (1985) for various particulate pollutants probably encompasses the deposition velocity of chloride (M. Lusis, pers. comm.). Various trace elements have been shown to have deposition velocities of 0.25 to 1.2 cm/s in Ontario. The average of these deposition velocities, 0.7 cm/s, is applied here to estimate dry deposition of chloride. Mean atmospheric chloride levels near Orangeville are about 0.45 ug/m^3, thus, dry deposition of chloride may be estimated at about 100 mg/m^2.

Thus, estimated annual dry deposition for phosphorus, nitrogen and chloride (mg/m^2) in the Orangeville area are:

- Total P 30
- Total N 300
- Cl^- 100

Based on these wet and dry deposition rates, total annual atmospheric deposition (mg/m^2) onto the 1.75 km^2 surface of the Orangeville Reservoir may be estimated as:

- Total P 45
- Total N 1,280
- Cl^- 325

3.4 Sediments

Three sediment samples (surface 2 cm) were collected by Ekman grab for nutrient analysis between June and August. All samples were collected from Station 2 in the east arm. Attempts to collect surficial sediments from the littoral areas covering most of the reservoir surface were not successful, due to the high density of aquatic plants. Samples were digested in 50% H_2SO_4 with Kjeldahl catalyst at 300 to 400°C until fuming, and dilutions of the digests were analyzed for total Kjeldahl nitrogen and total phosphorus using "Standard Methods" (APHA, 1985).

Rates of sediment accumulation were estimated for the reservoir from sediment cores. Three sediment cores were collected by diver using 4.7-cm (inside diameter) polycarbonate tubes from one area of the main basin of the reservoir having a water depth of about 1.5 m (mean depth of the reservoir). Sedimentation rates were estimated by identification of the soil/sediment boundary, corresponding to flooding of the reservoir in 1969. Soils were identified by a lighter brown colour and the presence of litter from the former cedar swamp. Sediments were darker brown and had no litter component. The soil/sediment interface occurred at core depths of 5 to 8 cm. After identification, the sediment layers were extruded, oven-dried and weighed. Sedimentation rates were then calculated on a mass per m^2 per year basis for each core. Phosphorus and nitrogen accumulation rates were then calculated based on average nutrient contents in the surficial sediments and on average sedimentation rates.

Nutrient concentrations in porewaters of surficial sediments were measured to evaluate the potential for remobilization to the water column. Porewaters were drained from samples of surficial sediments held in a fine mesh net, and centrifuged to remove suspended particulates. These samples were then analyzed for total phosphorus and nitrogen fractions.

3.5 Plant Harvesting

Plant harvesting was carried out in the Orangeville Reservoir from 11 June until 20 August (Figure 3.2). Harvesting was confined to the main portion of the reservoir (i.e., no harvesting in the east arm). A total of 673 harvester loads at about 1,000 lbs per load were harvested from the reservoir over this period. This represents an estimated 305 tonnes of plant biomass (wet weight). The harvested biomass consisted of 92.16% water (range 90.1 to 94.1%); thus, the total dry mass harvested was 23.6 tonnes. This is about 28% more than the 18.5 kg dry mass harvested in 1985.

A sample of harvested plant tissue (about 200 to 500 g) was collected weekly from the Orangeville Reservoir for nine weeks covering most of the harvest period. After collection, each sample was oven-dried at 70°C and stored until the completion of the harvesting program. The nine samples were composited into three samples corresponding to weeks 1-2-3, 4-5-6 and 7-8-9 in equal portions. Plant samples were then digested in the same manner as the sediments, and were analyzed for total phosphorus and total Kjeldahl nitrogen.

FIGURE 3.2: Upper Photo - ORANGEVILLE RESERVOIR PLANT HARVESTER
Lower Photo - UNLOADING OF PLANT BIOMASS FOR DISPOSAL

4.0 RESULTS AND DISCUSSION

4.1 Hydrology

Stream discharge data for Monora Creek and the East Tributary are detailed in Tables A2.1 and A2.2 (Appendix 2). The mean discharge of Monora Creek was 0.193 m^3/s, while that of the East Tributary was 0.033 m^3/s. These flows are in similar proportions to the watershed areas of these streams (Section 2.0), indicating a similar mean annual runoff in these streams (0.39 to 0.52 m/yr).

Stream flows in the North Tributary are relatively low (Table A2.3) given the 8.38 km^2 drainage area of the watershed. This indicates that a large fraction of precipitation in the North Tributary watershed is lost to evapotranspiration or to infiltration to groundwater. Based on the limited measurements available, the average discharge of the North Tributary is 89% of the discharge of the East Tributary. In general, discharges in the North Tributary visually appeared similar to or slightly less than discharges in the East Tributary during site visits for water quality sampling, suggesting that the measured discharge ratio of 89% is a reasonable estimate for most of the year (beginning with the spring thaw). The estimated mean annual discharge of the North Tributary is thus about 0.027 m^3/s, and the watershed runoff is about 0.1 m/yr. Estimated discharge volumes for intervals that generally encompass water sample collection periods (for loadings calculations) are given in Table A2.4.

About 4 km^2 of the reservoir drainage basin drains into the reservoir directly, without flowing into one of the three stream systems (Section 2.0). If the average watershed yield from these areas is equivalent to the area-weighted average of the yields of Monora Creek, and the East and North Tributaries, then these areas would have yielded 0.35 m over the year. This is equivalent to a total discharge of 1.4×10^6 m^3.

The total precipitation in 1986 was 1,179.6 mm at Environment Canada's Orangeville monitoring station (Environment Canada, pers. comm.). This rate of precipitation is about 40% of the long-term average at this station. Over the 1.75 km^2 surface area of the Orangeville Reservoir, the 1986 precipitation contributed a total of 2.06×10^6 m^3 to the reservoir surface.

Thus, hydrologic inputs (m^3) to the reservoir in 1986 may be summarized as follows:

• Monora Creek	6.098×10^6
• East Tributary	1.04×10^6
• North Tributary	8.6×10^5
• Direct Runoff	1.4×10^6
• Total Atmospheric Precipitation	2.06×10^6
TOTAL INPUTS	1.146×10^7

Monthly discharges from the south control structure for the years 1980-1986 are detailed in Table A2.5. In 1986, the total discharge from the control structure was 8.01×10^6 m^3, which is equivalent to an average discharge rate of 0.254 m^3/s.

Assuming no net change in the reservoir storage volume between the beginning and end of the year, inflow and outflow volumes should be equal. The discrepancy between total inflows and outflows may be partly explained by leakage through the dykes. The south dyke is rather porous, and seepage downstream has been observed by CVCA. In the original engineering design of the reservoir, leakage of about 1 cfs (0.03 m^3/s) through the south dam was expected. IEC (1981) estimated a loss of 0.014 to 0.057 m^3/s from each dyke, although CVCA hydrologists have found very little seepage loss into the Nottawasaga River, apparently because the north dyke is less porous than the south dyke. Engineering design estimates also indicated that a leakage of 0.25 cfs (0.007 m^3/s) was expected from the east arm to the Nottawasaga through the narrow ridge bordering the northwest shore of the east arm. If seepage from the south dyke averages 0.03 m^3/s, seepage from the east arm averages 0.007 m^3/s, and seepage from the north dyke is negligible, total seepage would account for 54% of the 2.05×10^6 m^3 discrepancy between total inputs and total outputs.

The recording device used to monitor outflow was inoperative for much of 1986, and outflow records are judged to be less accurate than those routinely achieved. CVCA hydrology staff estimate that 1986 records probably err on the low side due to unrecorded losses over the weir during peak flow periods. Total outflow in 1986 is calculated to be somewhat below the 1980-1985 average of 8.67×10^6 m^3 (calculated from Table A2.5), even though 1986 precipitation of 1,179.6 mm was about 40% higher than

the average of 843 mm for Orangeville. Streamflow in the Credit River at the Environment Canada gauging station downstream of Orangeville (Figure 2.1) averaged 0.632 m^3/s in 1986 (Environment Canada, pers. comm.), which is slightly above the annual average of 0.611 m^3/s for the years 1980 to 1985. It is reasonable to assume that the ratio of streamflow in 1986 to the mean streamflow for 1980 to 1985 are the same for the reservoir and the Environment Canada gauging station, indicating that the total outflow at the south dam in 1986 is about $8.67 \times 10^6 \times 0.632/0.611$, or 8.97×10^6 m^3. This implies that the actual outflow from the Orangeville Reservoir was probably about 12% higher than recorded by CVCA.

Evaporative losses from the surface of the reservoir are estimated at 800 mm/yr, based on evaportation rates given in the Hydrological Atlas of Canada for small lakes in this region of southern Ontario (Fisheries and Environment Canada, 1978). Over the 1.75 km^2 surface area of the Orangeville Reservoir, this represents an estimated annual loss of 1.4×10^6 m^3.

Based on the above outflow estimates, losses of water from the Orangeville Reservoir (m^3) are estimated as follows:

• South dyke control structure (measured)	8.01×10^6
• South dyke unrecorded overflow (inferred)	9.6×10^5
• South dyke leakage	9.5×10^5
• Leakage from East Arm (to Nottawasaga)	2.2×10^5
• Evaporative Loss from Reservoir Surface	1.4×10^6
TOTAL OUTPUTS	1.154×10^7

This estimated water loss from the reservoir balances very well with the estimated inflow volume given earlier in this subsection.

Chloride budgets may be used as a check on these values, although the small unquantified components of both the chloride inputs and outputs make a precise calibration impossible. Chloride data for the three tributaries are detailed in Table A2.6, and are applied in Tables A2.7, A2.8 and A2.9 to calculate 1986 chloride loadings from Monora Creek, the East Tributary and the North Tributary, respectively.

The three surface water sources contributed a total of 149.7 tonnes of chloride to the reservoir in 1986. Atmospheric loadings, at an annual bulk deposition rate of 325 mg/m^2 (Tang et al., 1986), contributed an estimated 0.57 tonnes of chloride to the 1.75 km^2 surface of the reservoir in 1986. Thus, chloride loadings to the reservoir from these sources totalled 150.3 tonnes in 1986. Chloride loadings from the 4.06 km^2 area of the reservoir drainage basin (15% of the total drainage land area) draining directly into the reservoir are unknown.

Total chloride export from the south control structure of the Orangeville Reservoir in 1986 is estimated at 158.5 tonnes (Table A2.10), based on measured outflow. Assuming that the outflow was actually 12% greater than the measured discharge (due to unrecorded weir overflow), an additional 19 tonnes of chloride are estimated to have been exported to the Credit River. Leakage through the south dyke at 0.03 m^3/s would account for an additional 17 tonnes, assuming the same volume-weighted mean chloride concentration as in the outflow. Similarly, leakage of 0.007 m^3/s to the Nottawasaga from the east arm would account for a chloride loss of 4 tonnes. Thus, total chloride export through these pathways is estimated at 198.5 tonnes.

The discrepancy between the 150.3 tonnes of chloride input, and 198.5 tonnes of chloride output, should be accounted for by the 4.06 km^2 that drains directly into the reservoir. If the hydrologic contribution of these areas is 1.4×10^6 m^3, as estimated earlier in this subsection, a mean chloride concentration of 34 mg/L in surface water from these areas would account for the 48 tonne imbalance in the chloride budget. This inferred mean chloride concentration is a reasonable value for the area in general, as it is within the range of the volume-weighted mean annual chloride concentrations found in Monora Creek (17 mg/L), the East Tributary (38 mg/L) and the North Tributary (10 mg/L).

Thus, the water budget estimated for the Orangeville Reservoir shows a good input-output balance based on both streamflow and chloride measurements, and can be used with a high degree of confidence in nutrient budget determinations.

4.2 Nitrogen and Phosphorus Budgets

4.2.1 Nutrient Inputs

Inputs of nitrogen and phosphorus to the Orangeville Reservoir, calculated from the water quality data given in Table A2.6, are detailed in Tables A2.7, A2.8 and A2.9 for the three inflowing watershed systems. On an annual basis, nutrient loadings from these sources may be summarized as shown in Table 4.1.

The nutrient contribution from direct drainage into the reservoir is calculated as the area-weighted average (17.9%) of the total annual loadings from Monora Creek, the East Tributary and the North Tributary watersheds.

The significance of nitrogen fixation as a nitrogen source in the Orangeville Reservoir is unknown. It has often been assumed that N-fixation by blue-green algae and bacteria is relatively insignificant in the nitrogen budget of freshwater systems, although the relative importance of N-fixation has been shown to vary widely (Wetzel, 1983). For example, 17.8% of the nitrogen income in Lake Mendota was found to be due to nitrogen fixation. Here, it is assumed that N-fixation and denitrification approximately balance in the Orangeville Reservoir, as they do in Lake Mendota (Wetzel, 1983), and that N-fixation and denitrification may be ignored in the input-output budget calculations for the reservoir.

The total surface water contribution of total nitrogen to the Orangeville Reservoir in 1986 was 12,108 kg, or 6% less than estimated for 1984 based on very limited sampling (Clarke-Whistler et al., 1985). The total phosphorus input of 336 kg from surface water is 22% less than the 1984 estimate.

4.2.2 Nutrient Export

Table A2.10 details monthly average nutrient concentrations at the Orangeville Reservoir outflow, and computes monthly export from the reservoir (excluding unmeasured losses at the dyke and seepage from the reservoir). Losses due to unmeasured outflow and seepage are assumed to vary directly with the magnitude of the estimated flows through these pathways (Table 4.1).

TABLE 4.1: NUTRIENT BUDGETS OF THE ORANGEVILLE RESERVOIR, 1986

	Inputs (kg)				
	NO_3-N	NO_2-N	TKN	TN	TP
Monora Creek	3,600	41	3,300	7,200	220
East Tributary	1,320	10	772	2,100	43
North Tributary	355	6.4	646	1,008	22.4
Direct Drainage	940	10	840	1,800	51
Atmospheric Deposition	-	-	-	2,240	79
TOTAL INPUTS	6,215	67.4	5,558	14,350	415
	Exports (kg)				
South Control Structure (measured)	1,412	48.3	3,747	5,207	158.5
Unmeasured Overflow	170	5.9	450	626	19.0
South Dyke Seepage	168	5.8	445	619	18.8
East Arm - Nottawasaga Seepage	39	1.3	103	143	4.4
TOTAL EXPORTS	1,789	61.3	4,745	6,595	201
Nutrient Retention Coefficient	0.71	0.09	0.15	0.54	0.52

Total export of phosphorus and all nitrogen compounds are considerably less than the quantities entering the reservoir in 1986, confirming the conclusion of Clarke-Whistler et al. (1985) that the reservoir acts as a nutrient sink. Retention coefficients were 0.52 for total phosphorus and 0.54 for total nitrogen, with most of the nitrogen retention accounted for by nitrate nitrogen (Table 4.1). The retention of nitrate and total nitrogen observed here (Table 4.1) agree with the corresponding retention reported by Clarke-Whistler et al. (1985) of 0.70 for nitrate and 0.54 for total nitrogen. A somewhat lower retention of phosphorus (0.40) was reported by Clarke-Whistler et al. (1985) than was observed in 1986. Total nutrient export from the Orangeville Reservoir was about 42% less for phosphorus and 19% less for total nitrogen in 1986 than reported by Clarke-Whistler for the years 1977-1984.

Most reservoirs act as nutrient sinks, since they promote settling of water column particulates and associated phosphorus and nitrogen. Phosphorus has been studied considerably more than nitrogen in this regard, as it is usually the limiting nutrient for primary productivity. Lakes and reservoirs are usually very efficient in retaining phosphorus, but this is dependent upon the flushing rate. Based on a review by Bird (1985), the average P retention in lakes and reservoirs with a flushing time of less than one year was 34% (flushing time of the Orangeville Reservoir was 1.5 to 2 months in 1986). The average P retention in 15 southern Ontario lakes was 44% (from Table 1 of Kirchner and Dillon, 1975). Bird (pers. comm.) recently calculated total P retention coefficients of 0.345 to 1.034 for three reservoirs on the Grand River system (Conestoga Lake, Belwood Lake and Guelph Lake), based on monitoring programs undertaken in 1978 and 1979 by the Grand River Conservation Authority. Bird estimated much lower phosphorus retention coefficients of 0.14 and 0.0 for Belwood Lake in 1984 and 1985, respectively. Upper Thames River Conservation Authority monitoring data demonstrated a combined retention coefficient for the Fanshawe and Wildwood Reservoirs of 0.36 for total phosphorus (unpublished UTRCA report). Thus, the phosphorus retention coefficient of 0.52 in the Orangeville Reservoir in 1986 is near the middle of the ranges of most retention coefficients reported for rapidly flushing lakes.

Data on nitrogen retention by reservoirs are very limited. An unpublished report by the UTRCA gives a retention coefficient of only 0.048 for total nitrogen in the combined Fanshawe and Wildwood Reservoirs. This contrasts with the much greater nitrogen retention of 0.54 for the Orangeville Reservoir in this study.

The nitrogen and phosphorus not exported from the reservoir is stored in various compartments in the reservoir, thereby reducing nutrient loadings to the upper Credit River. These nutrients may be stored in the sediments and in aquatic plant biomass.

4.2.3 Sediments and Nutrient Remobilization

Surface sediments of the Orangeville Reservoir are highly organic, and appeared to consist mainly of decaying aquatic plant biomass. The nitrogen and phosphorus concentrations of these sediments average 2.4 and 0.14%, respectively (Table A2.11).

Annual sedimentation rates, estimated from three sediment cores from one area of the reservoir, were found to range between 400 and 700 g/m^2, with a mean rate of 520 g/m^2. If this rate is average for the whole reservoir, an annual deposition of 12.5 g/m^2 of total nitrogen and 0.73 g/m^2 of total phosphorus would be expected, based on mean nutrient concentrations in surficial sediment. However, both sedimentation rate estimates are biased high, since they infer annual deposition of 2.8 times the quantity of nitrogen and 8.1 times the quantity of phosphorus retained by the reservoir. This implies that average sedimentation rates estimated for the 1969-1986 period are too high for 1986. A greater number of sediment cores and coring locations would probably be required to determine a reliable estimate of the whole-lake average sedimentation rate for the reservoir.

Water column data show that high phosphorus and Kjeldahl nitrogen levels occur periodically in bottom waters (Table A2.12). These higher concentrations were observed during a period of warm, relatively calm weather when wind-driven mixing was minimal. Even under these conditions, temperature stratification at the deepest point was not well defined, but dissolved oxygen concentrations were depleted to near zero within a metre of the bottom. Most of the Kjeldahl nitrogen released to the bottom waters under those conditions is probably ammonia formed during anaerobic decomposition. Phosphorus release is probably promoted by the reduction of iron and manganese to soluble forms. Porewater data (Table A2.12) confirm that soluble phosphorus and Kjeldahl nitrogen concentrations are periodically high in the sediment porewater.

Station 1, which was located in an unharvested area with heavy weed growth, demonstrated occasional dissolved oxygen depletion in bottom waters, but oxygen depletion was not as severe as at Station 2 in the deep hole (Table A2.12). Excessive nutrient generation and anaerobic conditions were not observed at Station 1, which is typical of much of the reservoir in terms of depth and plant growth, indicating that wind-driven mixing probably prevents anaerobic nitrogen and phosphorus mobilization over most of the reservoir area in summer. Anaerobic conditions may develop more extensively near the sediment-water interface under ice in winter and perhaps at night in summer due to respiration by the aquatic plant community, although no measurements were made to evaluate the extent of oxygen depletion under these conditions. Severe oxygen depletion apparently occurred in winter in the early years after reservoir formation, as evidenced by winter fish kills. Fish kills have not occurred recently, either due to a reduction in oxygen depletion, or to a shift in the fish community from stocked salmonids to warm-water species which may be more tolerant of low dissolved oxygen concentrations.

Thus, it is evident that Orangeville Reservoir sediments provide a dynamic pool of nutrients which act overall as a net sink for phosphorus and nitrogen, but under certain conditions may release nutrients back to the water column. The rate of release is greatly increased under anoxic conditions which occur intermittently in the deepest area in summer.

4.2.4 Aquatic Macrophytes

Clarke-Whistler et al. (1985) surveyed the aquatic macrophytes of the Orangeville Reservoir in 1984, and found total dry-weight biomasses of 920 to 2,700 g/m^2 in the summer in areas less than 2.5 m deep. The average biomass of tissues excluding roots (i.e, the harvestable portion) was found to average 627 g/m^2, or $5.02x10^5$ kg for the entire surface of the reservoir. Biomasses observed in 1986 were judged to be similar to those found in 1984, although Elodea appeared to constitute a greater fraction of the total biomass in 1986 than in 1984, when nearly all of the plant biomass was Myriophyllum.

Nutrient concentrations in the harvested plant material averaged 1.58% nitrogen and 0.25% phosphorus (Table A2.12). Concentrations showed no consistent seasonal trends

over the harvesting period. This average nitrogen concentration was less than the 2.42% reported by Clarke-Whistler et al. (1985). Phosphorus concentrations in 1986 and 1984 were in closer agreement (0.21% in 1984). A shift to greater Elodea densities may have contributed to the change in plant nitrogen levels.

Gerloff and Krumbholz (1966) have shown a relationship of aquatic plant yield to the amount of a particular nutrient present when all other environmental requirements are met. The amount of plant biomass produced increases almost proportionately with the amount of the element supplied until the latter ceases to be limiting. Further nutrient addition then causes no further increment in biomass, though the quantity of nutrient incorporated into the plant tissue continues to increase, a phenomenon known as "luxury consumption". This means that, when a plant is limited by a particular nutrient, the concentration in the tissues will tend to correspond to the fundamental quantity required for metabolism while the yield of the plant increases. When the nutrient is no longer limiting, increase in nutrient quantity produces no greater yield, but only storage of the element. The transition point, at which this storage without additional plant growth starts to occur, defines a critical concentration. If plants contain less of the nutrient, it is a reasonable presumption that they are limited by the nutrient. The critical concentrations have been established as 1.3% for nitrogen and 0.14% for phosphorus (Gerloff and Krumbholz, 1966). Based on 1984 and 1986 data, nitrogen and phosphorus concentrations in plant tissues from the Orangeville Reservoir were above the established growth limiting concentrations, indicating that production is probably not limited by these nutrients.

The pool of nutrients in the harvestable portion of the plant community, calculated from the average plant nutrient contents and on the estimated standing crop of 5.02×10^5 kg, is 7,932 kg of total nitrogen, and 1,255 kg of total phosphorus. This total nitrogen inventory is approximately equal to the 7,750 kg of total nitrogen retained by the reservoir in 1986, indicating that aquatic plants may play an important role in removal of nitrogen from the water column. The total phosphorus inventory in the plant community is 5.8 times greater than the 216 kg of phosphorus retained by the reservoir in 1986, reaffirming the conclusion of Clarke-Whistler et al. (1985) that most of the phosphorus requirements of the plant community must be met by uptake from the sediment rather than from the water column. It is generally accepted that rooted macrophytes can meet their phosphorus and nitrogen needs by both aqueous uptake and root uptake (Barko et al., 1986).

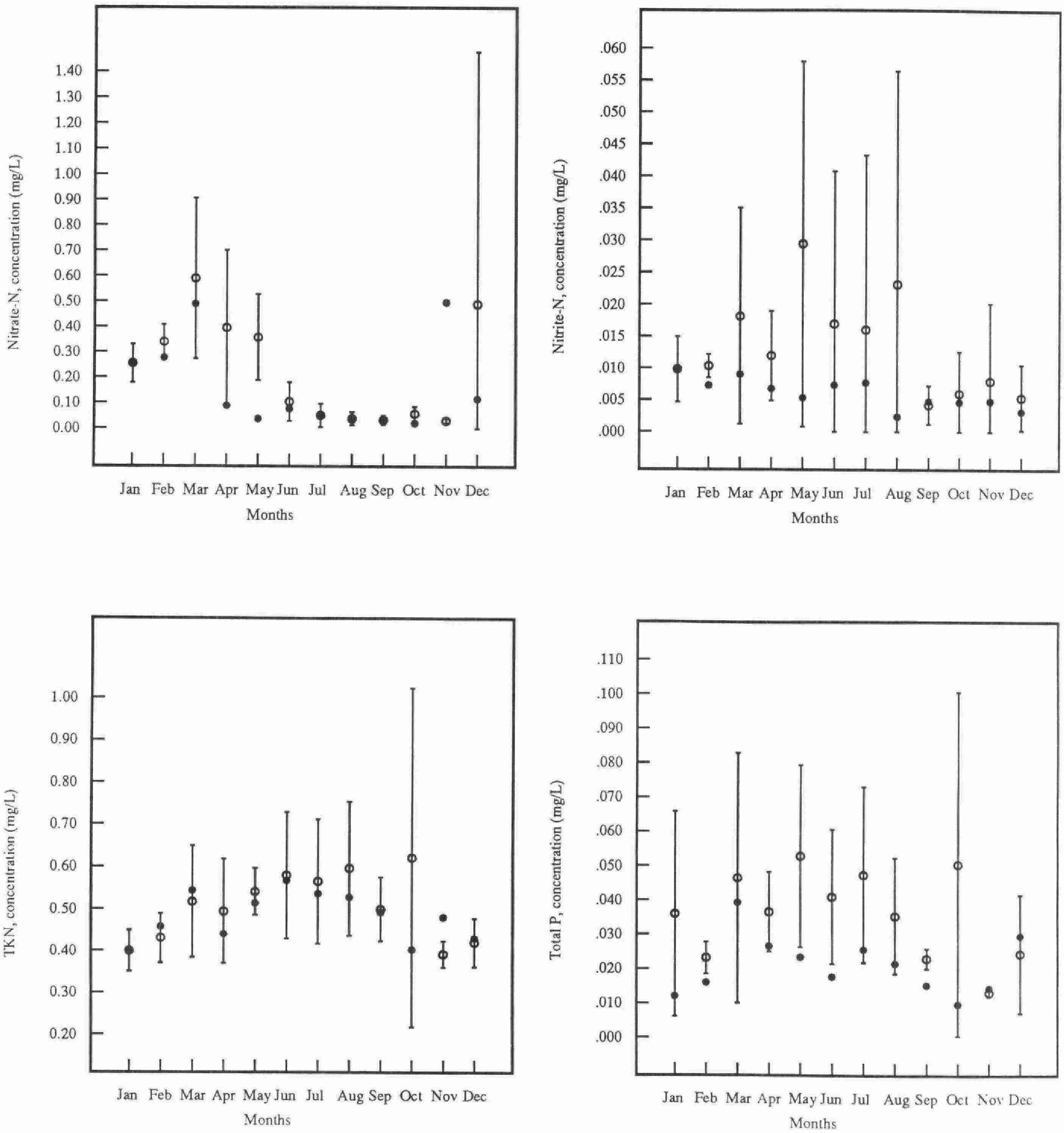
Aquatic plants also represent a potential source of nutrients to the water column. Nutrient losses can occur due to metabolic excretion, senescence (leaching) and microbial decay. The greatest losses appear to occur during senescence and decay (Carpenter, 1980) and can be quite substantial, particularly in eutrophic systems with a high turnover of biomass (Wetzel, 1983). For example, Landers (1979) found substantial increases in water column phosphorus and nitrogen during decay of milfoil. Peverly and Johnson (1979) found that, during the fall, senescence of Elodea resulted in substantial nitrogen releases to the water column, while phosphorus releases were not observed.

The relative importance of the plant community in uptake and release of nutrients to and from the water column in the Orangeville Reservoir may be evaluated by examining seasonal patterns in nutrient concentrations. As shown in Figure 4.1, average nitrate concentrations are highest and most variable in winter and spring, and are suppressed and relatively constant from June to October, suggesting that releases occur during senescence, and uptake by the plants occurs in the growing season. Average nitrate values in 1986 were usually lower than in the preceding years in the winter, early spring and late fall, but this cannot be interpreted as an effect of plant harvesting since the trend occurs quite consistently during the pre-harvest period. Kjeldahl nitrogen levels tend to rise during the growing season, possibly due to increased biodegradation and release of ammonia during the warmer months. Seasonal patterns of phosphorus concentrations show no clear seasonality that can be related to the period of plant growth, suggesting that phosphorus uptake is primarily from the sediments, and that plant die-off does not release an appreciable quantity of phosphorus to the water column. Similarly, a lack of seasonal variation in dissolved phosphorus concentrations was reported by Clarke-Whistler et al. (1985). The phosphorus released intermittently and locally to bottom waters during summer stagnation (Tables A2.12) does not result in a consistent increase in phosphorus concentrations at the reservoir outlet (Figure 4.1).

4.2.5 Management Implications of Plant Harvesting

The state of knowledge on the nutritional ecology of aquatic macrophytes has undergone considerable evolution in recent years. For example, at a conference in the late 1970's, it was concluded that plant harvesting could substantially reduce the phosphorus content of lakes, and participants foresaw an increase in the application of harvesting for mitigating lake eutrophication (Breck et al., 1979). Participants at a 1984 workshop on

FIGURE 4.1
MONTHLY MEAN NUTRIENT CONCENTRATIONS AT THE SOUTH DAM OUTFLOW, ORANGEVILLE RESERVOIR



o Mean monthly concentration, 1980-85 (Bars = 1 S.D.)

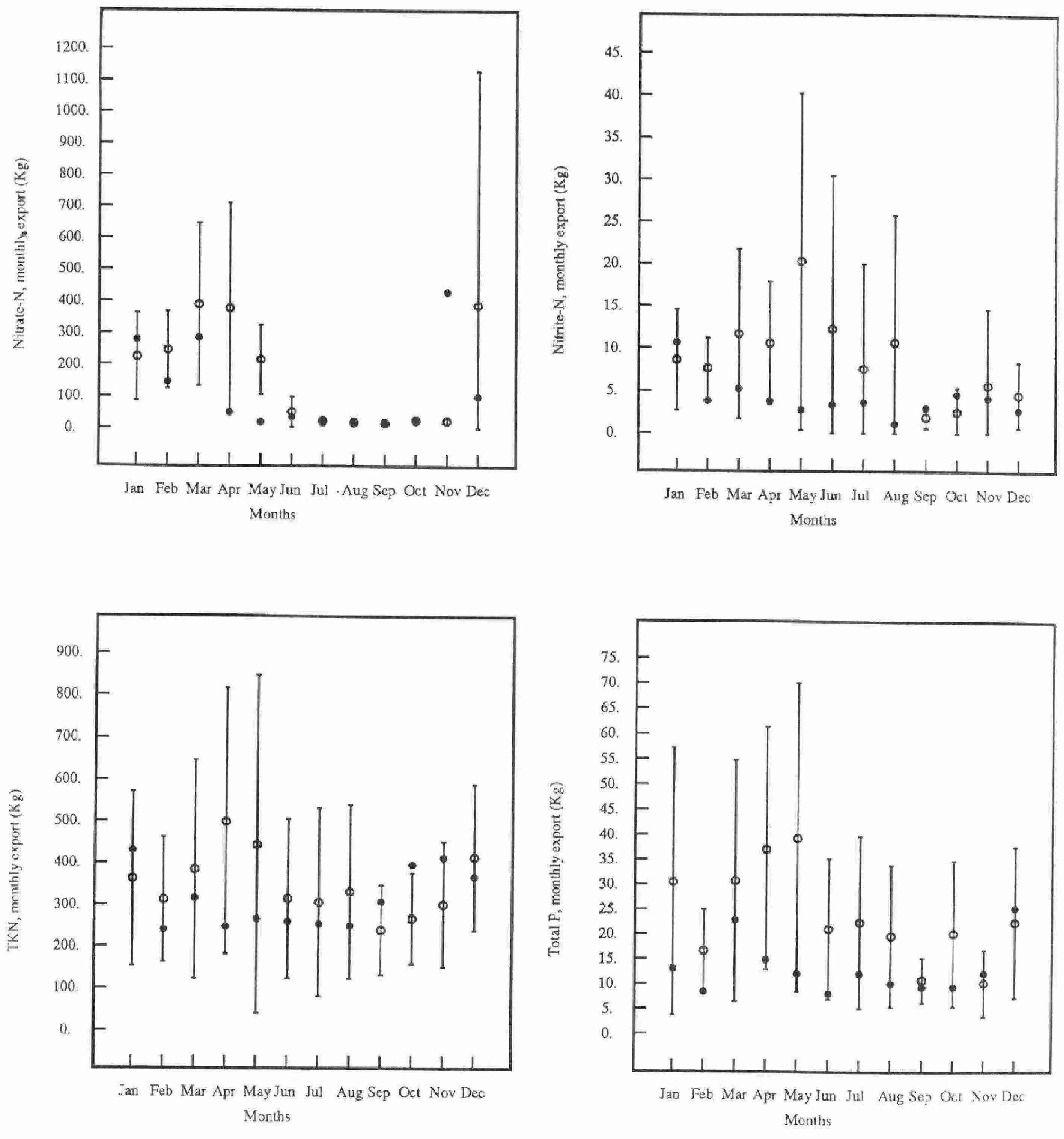
• Monthly concentration, 1986.

the topic (cited in Barko et al., 1986) felt that harvesting was useful mainly in enhancement of the recreational value of lakes, while nutrients in aquatic systems could not be effectively managed through plant harvesting alone.

Clarke-Whistler et al. (1985) determined that removal of about 200 tonnes dry mass of plant material per season should be achievable in the Orangeville Reservoir, and that removal of this quantity may substantially reduce downstream nitrogen export to the Credit River. The 23.6 tonnes removed in 1986 is only 12% of this quantity. Much of the discrepancy is due to the method of off-loading harvested plant material. The 200 tonne estimate was based on MOE harvesting experience in Chemung Lake, Ontario, where harvested biomass was off-loaded on the shore at locations that minimized travel distances. At the Orangeville Reservoir, plants are off-loaded at one location, and most of the harvesting time is actually spent in travelling between the harvesting location and the off-loading site.

The total nitrogen removal in the 1986 harvest was 360 kg. As noted earlier, the seasonal decay of plants appears to result in release of nitrogen in the form of nitrate to the water column (Figure 4.1). Removal of plant biomass should, therefore, effectively reduce the pool of plant-nitrogen available for remobilization and downstream transport. However, the 360 kg of nitrogen actually removed in plant biomass in 1986 represents only a small fraction of the 7,750 kg of total nitrogen retained by the reservoir, and was probably insufficient to achieve a significant reduction in downstream export to the Credit River. Indeed, total monthly export of nitrate from the south control structure of the Orangeville Reservoir in November-December following the 1986 harvest does not differ from the average export over the 1980-1985 period (Figure 4.2). Export of Kjeldahl nitrogen, the other major nitrogen fraction, actually tended to be slightly higher in post-harvest months in 1986 than corresponding average export rates for 1980 to 1985 (Figure 4.2). Similarly, total annual export of nitrogen fractions from the Orangeville Reservoir fell within the range of annual export calculated for 1980 to 1985 (Figure 4.3), and this situation is unaffected when export is corrected for discharge volume (Figure 4.4). Thus, it can be concluded that harvesting at the present level of efficiency is ineffective in substantially reducing downstream export of nitrogen. A major increase in harvesting efficiency (five- to ten-fold) may be sufficient to reduce nitrogen loadings from the reservoir to a degree that can be measured in a monitoring study such as this.

FIGURE 4.2
MONTHLY MEAN NUTRIENT EXPORT FROM THE SOUTH DAM CONTROL STRUCTURE, ORANGEVILLE RESERVOIR



o Mean monthly export, 1980-85 (Bars = 1 S.D.)

• Monthly export, 1986.

FIGURE 4.3
TOTAL ANNUAL NUTRIENT EXPORT FROM THE SOUTH DAM CONTROL STRUCTURE, ORANGEVILLE RESERVOIR

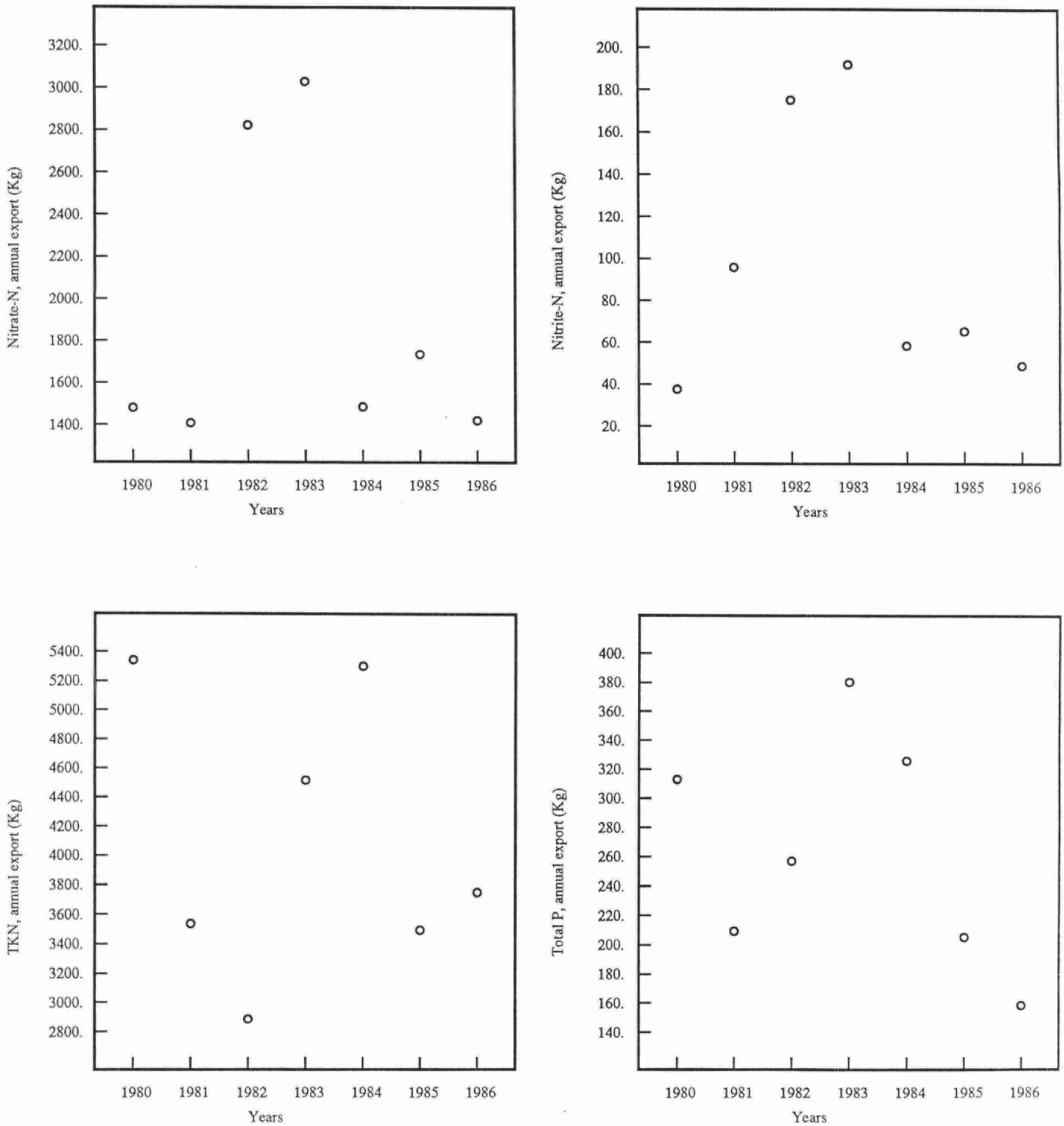
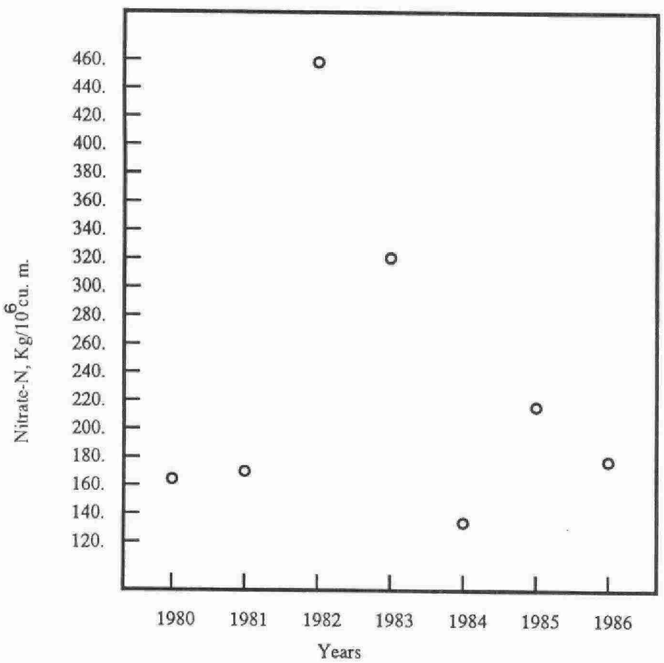
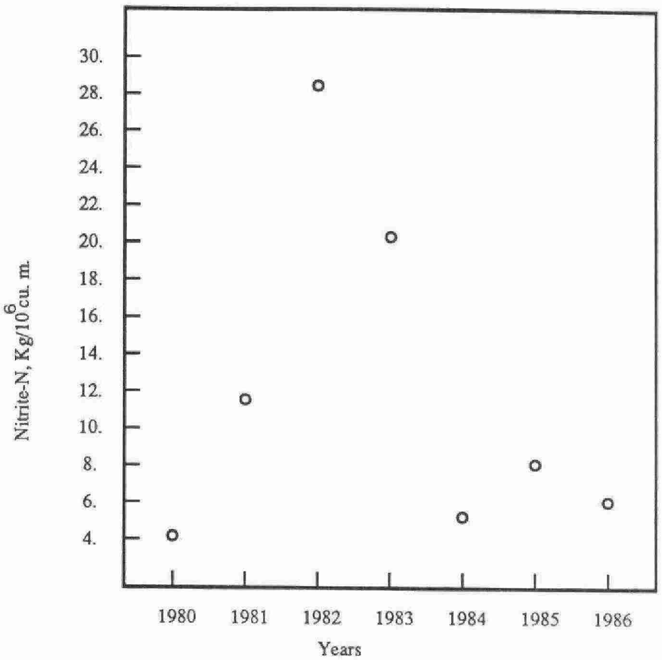
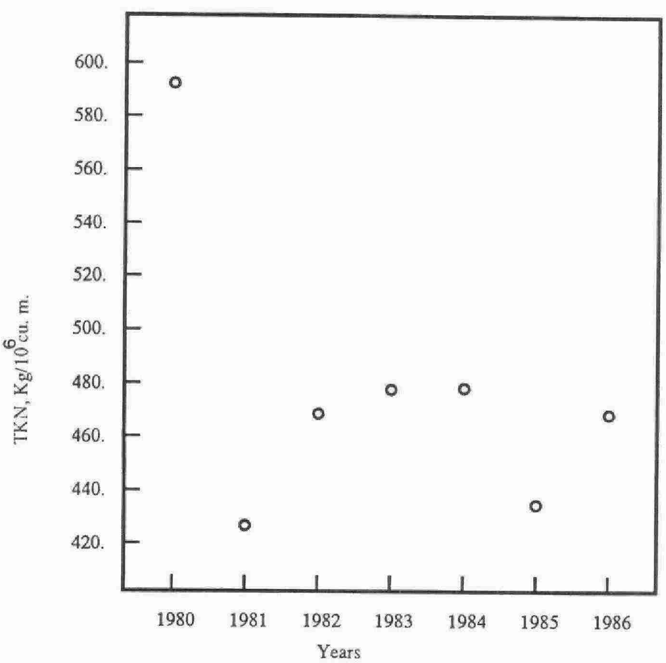
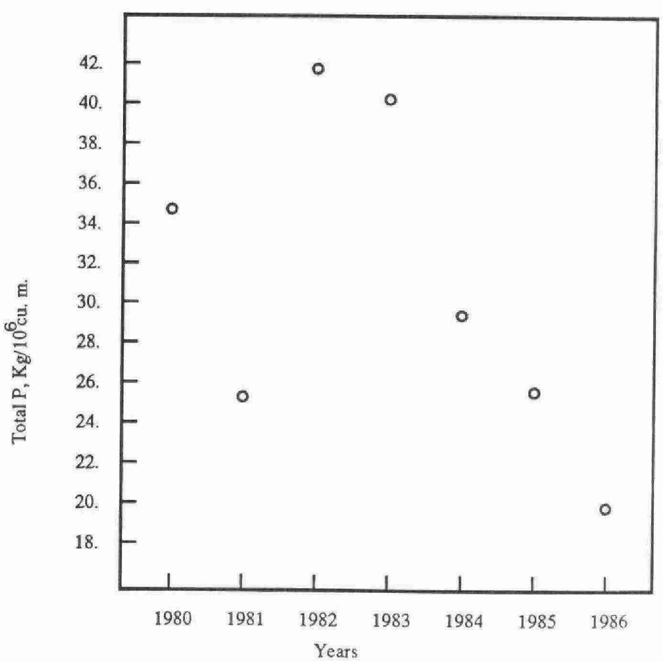


FIGURE 4.4
ANNUAL NUTRIENT EXPORT (KG) PER MILLION CUBIC METRES OF DISCHARGE RECORDED AT THE ORANGEVILLE RESERVOIR OUTFLOW









Most of the nitrate export from the reservoir (about 80 to 85%) occurs during the period of plant decay between November and April (calculated from Figure 4.2). Therefore, removal of 200 of the estimated 500 tonnes of harvestable plant tissue in the reservoir may effect a reduction of up to 32% (80% x 40%) in this downstream nitrate load. Some of the Kjeldahl nitrogen exported from the reservoir may also be attributed to plant decay, based on the observed increase in TKN export from October to April (Figure 4.2). It is reasonable to expect that removal of 40% of the plant biomass would result in a reduction of about 0.6 tonnes per year of nitrate nitrogen export and perhaps 0.3 to 0.4 tonnes per year of the TKN export, or roughly 0.9 to 1 tonnes per year of total nitrogen.

Phosphorus export, on the other hand, was lower during most months in 1986 than calculated averages for 1980 to 1985 (Figure 4.2), and annual export was lower than in any of the preceding six years, both on an absolute basis (Figure 4.3) and on a discharge-corrected basis (Figure 4.4). This is a function of the lower average phosphorus concentrations found at the outflow in 1986 (Figure 4.1). A general decline in annual phosphorus loadings from the Orangeville Reservoir is suggested by Figures 4.3 and 4.4, although continued monitoring and evaluation of the database would be required for verification. Annual changes in phosphorus export may be attributed either to changes in loadings to the reservoir, or to changes in phosphorus retention by the reservoir.

Aquatic plants in the reservoir apparently meet their phosphorus requirements from the sediments, and do not return this phosphorus to the water column during senescence (Subsection 4.2.4); thus, plant harvesting does not offer any potential for reducing downstream phosphorus export from the reservoir. Over the long-term, however, plant harvesting could gradually decrease the sedimentary pool of phosphorus. The removal of only 23.6 tonnes of biomass in 1986 removed 59 kg of phosphorus, or 27% of the phosphorus retained by the reservoir. An increase of more than four-fold in the plant harvest would result in a net phosphorus deficit in the reservoir and a decrease in sediment phosphorus concentrations. Over the long-term, this could result in a gradual oligotrophication of the system, and reduced plant growth. A reduction in plant biomass should lead to a reduction in community respiration and an increase in water circulation which could result in higher dissolved oxygen concentrations in bottom waters during critical periods, and a decrease in anaerobic phosphorus release from the sediments. Lower sediment phosphorus concentrations should lead to reductions in waterborne particulate phosphorus generated due to wind-driven mixing and sediment resuspension,

thereby reducing phosphorus export. Moreover, a phosphorus-limited system would be expected to retain phosphorus more efficiently, resulting in a further reduction in downstream loadings. Many years (perhaps decades) of intensified plant harvest would probably be required to deplete the phosphorus pool in the active sediment layer due to the high sediment phosphorus concentrations. However, at the present rate of harvest, no depletion would be expected.

4.2.6 Significance of the Reservoir as a Nutrient Source

Recognition of an eutrophication problem in the upper Credit River led concurrently to the implementation of the weed harvesting program, and to the incorporation of increased phosphorus and nitrogen control measures in the Orangeville STP expansion. It was inferred by the MOE (1981) that nitrogen was the limiting nutrient in the upper Credit, based on an absence of nuisance algal growth in the presence of relatively high phosphorus concentrations downstream of the Orangeville STP. The expanded STP came on-line in May 1985.

The new STP facility has achieved loading reductions of about 75% for total phosphorus and 50% for total nitrogen (Table 4.2). Thus, phosphorus loadings have been reduced proportionally more than nitrogen loadings. It has been reported that inorganic N/P ratios of less than 10 (on a mass basis) imply nitrogen limitation, while ratios greater than 17 imply phosphorus limitation in lakes (Forsberg et al., 1978). These same relationships may not apply to rooted plant communities that rely, to varying degrees, on the sediment for nutrient supplies, but may apply to epibenthic and waterborne algae in the Credit River. The inorganic N/P ratio in STP plus reservoir loadings, based on nitrate nitrogen and total phosphorus, has changed from about 8 prior to upgrading of the STP, to 27 in 1986 (Table 4.2), implying a possible shift from nitrogen to phosphorus limitation in the upper Credit. In a long-term program to monitor nutrient concentrations in the Orangeville marsh downstream of the STP, Fitchko et al. (1987) found marked declines in plant tissue phosphorus levels since the implementation of nutrient control measures at the STP. In 1986, phosphorus concentrations in coontail fell below the growth-limiting concentration of 0.14% identified by Gerlogg and Krumbholz (1966) for the first time since the beginning of annual monitoring in 1982. This substantial reduction in phosphorus loadings, the corresponding change in N/P ratios in the nutrient load and the observed response in the downstream aquatic plant community

TABLE 4.2: AVERAGE NUTRIENT LOADINGS (t/yr) FROM THE ORANGEVILLE RESERVOIR AND THE ORANGEVILLE STP

Nutrient	Orangeville Reservoir		Orangeville STP		
	1980-85[1]	1986	1975-80[3]	1985	1986
Total Phosphorus	0.28	0.20	2.6	0.73	0.66
Nitrate	2	1.75	27	20.3	21.5
Total Kjeldahl Nitrogen	4.2	4.6	19	3.1	2.2
Total Nitrogen[2]	6.3	6.5	46	23.4	23.7

[1] Calculated as 1.1 times the export shown in Figure 4.3, to account for the estimated loss due to seepage at the south dyke.

[2] TKN + NO_3 + NO_2 for reservoir, TKN + NO_3 for STP.

[3] From IEC (1981).

suggest that production in the upper Credit may now be limited more by phosphorus than by nitrogen.

The contribution of the Orangeville Reservoir to present total nutrient loadings is substantial - about 23% for phosphorus and 22% for total nitrogen (Table 4.2). As indicated earlier, plant harvesting is ineffective in reducing phosphorus export, at least in the near-term, because the plant community of the reservoir derives most of its phosphorus from the sediment. Over the longer term, however, plant harvesting of about 100 tonnes per year or more may be expected to reduce sediment phosphorus concentrations to levels that may limit plant growth, reduce remobilization to the water column, and lead to improved dissolved oxygen levels during periods of stagnation.

A relatively immediate reduction in nitrogen loadings, particularly in the form of nitrate, may be achieved by plant harvesting. A harvest of 200 tonnes dry mass of plant tissue, a quantity about 8.5 times greater than the 1986 harvest, could potentially remove up to 3.2 tonnes of nitrogen from the reservoir. As noted in the preceding subsection, this may reduce downstream export by about 1 tonne of nitrogen per year. Based on present loadings to the upper Credit (Table 4.2), this removal would represent a very small fraction (roughly 3%) of total loadings to the upper Credit River.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. The Orangeville Reservoir acts as a sink for phosphorus and nitrogen. Of the nutrients entering the reservoir, 54% of total nitrogen and 52% of total phosphorus are retained by the reservoir, thereby reducing downstream export to the Credit River.

2. The nitrogen and phosphorus retained by the reservoir are removed either directly by sedimentation or through bioconcentration by the aquatic plant community. Total nitrogen and phosphorus concentrations in the surficial sediments average 2.4% and 0.14%, respectively.

3. Bottom waters in the deepest part of the reservoir become intermittently depleted in oxygen in summer, resulting in releases of phosphorus and nitrogen (probably as ammonia) from the sediments. The degree of oxygen depletion in bottom waters at the shallow depths (less than 3 m) typical of most of the reservoir, appears to be insufficient to result in substantial nutrient remobilization.

4. Harvested plant tissues contained an average of 1.58% nitrogen and 0.25% phosphorus on a dry weight basis. These concentrations are higher than threshold concentrations identified in the literature as indicating nutrient limitation. Thus, aquatic plant production is apparently not limited by nutrient availability in the reservoir.

5. The inventory of nitrogen in the plant community of the reservoir is close to the quantity of nitrogen retained by the reservoir, indicating that plants may be important in nitrogen removal from the water column. This removal of nitrogen is supported by the observation that bioavailable nitrate nitrogen is depleted in the water column during the growing season. Some of this accumulated nitrogen is released back to the water column during senescence and decay in late fall, winter and early spring, as evidenced by higher nitrate concentrations.

6. The inventory of phosphorus in the plant community is about six times greater than the quantity of phosphorus retained by the reservoir, and exceeded the annual phosphorus supply to the reservoir by about three times. Thus, the phosphorus requirements of the aquatic plants must be met primarily by uptake from the surficial sediments. This is further supported by the lack of phosphorus depletion in the water column during the growing season.

7. Harvesting of 23.6 tonnes dry mass of plant tissue from the reservoir in 1986 resulted in no measurable effect on nutrient export from the reservoir to the Credit River. This biomass represents less than 5% of the total standing crop in the reservoir during the growing season.

8. Removal of 200 tonnes of biomass would be expected to reduce the downstream nitrate export by about 32%, and total nitrogen export would be reduced by an estimated 1 tonne per year. This rate of harvest would require a large increase in harvesting efficiency that may be impractical.

9. Phosphorus export would be initially unaffected by an increase in plant harvest, since phosphorus uptake is from the sediment. An increase of four-fold or more in the harvest would result in a phosphorus deficit in the reservoir (removal would exceed supply). This should lead to a depletion in phosphorus concentrations in the surficial sediments that should, over the long-term, result in the gradual oligotrophication of the reservoir and a decrease in phosphorus export.

10. The Orangeville Reservoir presently accounts for about 23% of the phosphorus loading and 22% of the total nitrogen loading to the upper Credit River, based on combined loadings from the reservoir and the Town of Orangeville STP. Removal of 1 tonne per year of nitrogen from downstream export through a greatly increased harvesting effort would represent a reduction in the total (STP + reservoir) nitrogen loading of only 3%. A decrease in downstream phosphorus export may be achieved through long-term harvesting, but the magnitude of this decrease is unknown.

11. Recent improvements in treatment efficiencies at the Orangeville STP have achieved reductions of 75% in phosphorus loadings and 50% in nitrogen loadings. This has resulted in a marked increase in the inorganic N/P ratio in total loadings to the upper Credit, implying a probable shift from nitrogen to phosphorus limitation in primary producers in the system. This hypothesis is supported by declines in tissue phosphorus concentrations in coontail living downstream of the STP to levels that suggest phosphorus limitation.

12. The overall feasibility of plant harvesting in controlling nutrient export from small reservoirs in southern Ontario depends on the relative significance of nutrient export in the overall nutrient budget of the downstream watershed. Reductions in sediment phosphorus concentrations may be achievable in long-term harvesting in reservoirs such as Orangeville where plants derive their phosphorus from the sediments. If phosphorus removal by harvesting exceeds phosphorus retention, gradual oligotrophication and an increase in phosphorus retention should result. Measurable decreases in nitrogen export may be achievable by plant harvesting, although the amount of harvesting required may necessitate a very large effort that exceeds the limits of practicality.

5.2 Recommendations

1. If further reductions in nutrient loadings to the upper Credit River are desirable from a watershed management perspective, nutrient control procedures should be focussed primarily on phosphorus because phosphorus appears to be limiting to primary production since completion of the new Orangeville STP.

2. Because large inventories of phosphorus exist in the aquatic plant community and in the sediments of the Orangeville Reservoir, and because a substantial portion of the total phosphorus loading to the upper Credit originates from the reservoir, it may be useful to further investigate the feasibility of reducing phosphorus export through reducing sediment phosphorus concentrations by plant harvesting. Further study of sediment phosphorus exchange processes and the role of macrophytes in the process would be useful in evaluating the feasibility of plant harvesting in reducing phosphorus export.

3. If continued plant harvesting is desirable from a reservoir management perspective, means of increasing the harvest by at least four-fold should be investigated. Efforts here should focus on minimizing travel time for the harvester through barging or booming the harvested plants to shore, or by establishing multiple shoreline locations for off-loading.

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APPENDIX 1

Inter-Laboratory Comparison

APPENDIX 1: INTER-LABORATORY COMPARISON

Table A1.1 compares the results of outflow sample analyses by the two participating laboratories. There are no split samples included in this comparison. Rather, water quality data for the same survey period are simply compared as a general inter-laboratory check.

Phosphorus and chloride data from the BEAK laboratory, in all cases, fell within the concentration ranges reported by the MOE for the corresponding periods. The agreement for TKN was reasonable, although the BEAK result for the 21 January sample was slightly greater than the highest value reported by the MOE for the same period. One nitrate value and one nitrite value from the BEAK analyses (01 May sample) were below the concentration ranges given by the MOE for the same period, although the BEAK results fell close to or within concentration ranges found in MOE analyses from March to July samples.

Based on these comparisons, the agreement in analytical results from the two laboratories is excellent for total phosphorus and chloride, and is reasonable for nitrogen compounds. Thus, the two data sets are judged to be compatible, and can be used in the determination of input-output budgets.

TABLE A1.1: COMPARISON OF ORANGEVILLE RESERVOIR WATER QUALITY DATA FROM SAMPLES ANALYZED BY BEAK CONSULTANTS AND BY MOE IN 1986

Sample Period	Concentrations (mg/L)				
	NO_3-N	NO_2-N	TKN	TP	Cl^-
21 Jan (BEAK)	0.26	0.006	0.53	0.010	16.2
Jan-Feb (n=7) (MOE)	0.240-0.324	0.004-0.0115	0.36-0.49	0.009-0.017	8.5-25.0
01 May (BEAK)	LT 0.01	0.002	0.39	0.022	15.0
Apr-May (n=5) (MOE)	0.0335-0.140	0.0035-0.010	0.39-0.61	0.022-0.028	15.0-16.75
Mar-Jul (n=11) (MOE)	0.004-0.610	0.0025-0.010	-	-	-

APPENDIX 2

Detailed Environmental Data Tabulations

TABLE A2.1: ESTIMATED DISCHARGE IN MONORA CREEK IN 1986

Date	Interval Volume (m^3)	Mean Discharge (m^3/s)
Jan 01-17	1.51×10^5	0.106
Jan 17-21	8.55×10^4	0.248
Jan 21-22	3.07×10^4	0.365
Jan 22-29	1.18×10^5	0.195
Jan 29-03 Feb	1.75×10^4	0.041
Feb 03-05	5.10×10^3	0.030
Feb 05-06	8.51×10^3	0.099
Feb 06-09	3.25×10^4	0.126
Feb 09-12	2.07×10^4	0.080
Feb 12-19	3.51×10^4	0.058
Feb 19-26	2.90×10^4	0.048
Feb 26-05 Mar	2.90×10^4	0.048
Mar 05-09	2.26×10^4	0.066
Mar 09-11 (7:30)	6.96×10^4	0.445
Mar 11-11 (12:30)	1.53×10^4	0.850
Mar 11-12	6.20×10^4	0.718
Mar 12-14	7.17×10^4	0.415
Mar 14-21	3.41×10^5	0.572
Mar 21-26	1.31×10^5	0.304
Mar 26-03 Apr	2.49×10^5	0.354
Apr 03-11	1.64×10^5	0.244
Apr 11-24	3.18×10^5	0.280
Apr 24-08 May	1.91×10^5	0.158
May 08-23	1.54×10^5	0.117
May 23-05 June	1.50×10^5	0.135
June 05-18	1.08×10^5	0.096
June 18-25	5.48×10^4	0.092
June 25-08 July	8.82×10^4	0.079
July 08-11	1.46×10^4	0.057
July 11-24	8.05×10^4	0.072
July 24-01 Aug	5.92×10^4	0.085
Aug 01-14	9.24×10^4	0.084
Aug 14-28	2.95×10^5	0.241
Aug 28-11 Sept	2.01×10^5	0.169
Sept 11-25	6.06×10^5	0.501
Sept 25-09 Oct	5.48×10^5	0.452
Oct 09-24	3.88×10^5	0.299
Oct 24-07 Nov	3.22×10^5	0.264
Nov 07-21	2.55×10^5	0.214
Nov 21-05 Dec	1.85×10^5	0.153
Dec 05-31	2.98×10^5	0.130
TOTAL	6.098×10^6	Mean = 0.193

TABLE A2.2: ESTIMATED DISCHARGE IN THE EAST TRIBUTARY, 1986

Date	Internal Volume (m^3)	Mean Discharge (m^3/s)
Jan 01-17	21,168	0.014
Jan 17-20	7,854	0.0303
Jan 20-21	2,938	0.034
Jan 21-29	11,059	0.016
Jan 29-03 Feb	6,912	0.016
Feb 03-12	8,087	0.0104
Feb 12-19	4,385	0.0073
Feb 19-26	4,536	0.0075
Feb 26-05 Mar	3,024	0.007
Mar 05-09	2,074	0.006
Mar 09-11 (9:00)	13,479	0.078
Mar 11-11 (14:30)	7,380	0.205
Mar 11-12	10,323	0.155
Mar 12-18	23,846	0.046
Mar 18-26	49,075	0.071
Mar 26-03 Apr	18,014	0.0695
Apr 03-11	20,736	0.030
Apr 11-17	15,811	0.0305
Apr 17-24	22,075	0.0365
Apr 24-01 May	18,144	0.030
May 01-08	13,305	0.022
May 08-15	10,282	0.017
May 15-20	10,360	0.024
May 20-01 Jun	26,957	0.026
Jun 01-11	23,328	0.027
Jun 11-18	18,144	0.03
Jun 18-03 Jul	31,104	0.024
Jul 03-10	11,491	0.019
Jul 10-17	16,934	0.028
Jul 17-24	18,144	0.03
Jul 24-30	11,923	0.023
Jul 30-06 Aug	12,701	0.021
Aug 06-14	11,750	0.017
Aug 14-20	12,960	0.025
Aug 20-28	29,030	0.042
Aug 28-04 Sep	14,898	0.046
Sep 04-11	35,986	0.0595
Sep 11-18	35,078	0.058
Sep 18-25	26,611	0.044
Sep 25-01 Oct	33,178	0.064
Oct 01-09	50,112	0.0725
Oct 09-15	36,288	0.070
Oct 15-24	52,488	0.0675
Oct 24-02 Nov	43,546	0.056
Nov 02-07	19,656	0.0455
Nov 07-21	48,384	0.040
Nov 21-05 Dec	44,755	0.035
Dec 05-31	69,435	0.03
TOTAL	1.040×10^6	0.033

TABLE A2.3: NORTH TRIBUTARY DISCHARGE MEASUREMENTS AND COMPARISONS WITH EAST TRIBUTARY DISCHARGE

Date	Discharge (m^3/s)	East Tributary Discharge (m^3/s)	North/East Discharge Ratio
24 April	0.0265*	0.0194*	1.36
15 May	0.009*	0.022*	0.41
01 October	0.0699*	0.078**	0.90
Mean Ratio			0.89

* Measured flows.

** Flow estimated from gauge height.

TABLE A2.4: ESTIMATED DISCHARGE* IN THE NORTH TRIBUTARY, 1986

Date	Interval Volume (m^3)
Jan 01-05 Mar	$5.5x10^3$**
Mar 05-11	$2.0x10^4$
Mar 11-21	$4.9x10^4$
Mar 21-03 Apr	$4.1x10^4$
Apr 03-24	$5.2x10^4$
Apr 24-08 May	$2.8x10^4$
May 08-20	$1.8x10^4$
May 20-11 Jun	$4.5x10^4$
Jun 11-25	$2.7x10^4$
Jun 25-10 Jul	$2.9x10^4$
Jul 10-20	$1.9x10^4$
Jul 20-27	$1.3x10^4$
Jul 27-06 Aug	$1.7x10^4$
Aug 06-28	$4.8x10^4$
Aug 28-25 Sep	$1.0x10^5$
Sep 25-07 Nov	$2.1x10^5$
Nov 07-31 Dec	$1.4x10^5$
TOTAL	$8.6x10^5$

* Estimated to be 89% of the East Tributary discharge. Direct runoff is 48.4% of the North Tributary discharge, based on an equal aerial yield assumption.

** Based on an estimated discharge of 0.001 m^3/s.

TABLE A2.5: MONTHLY AND ANNUAL DISCHARGE RECORDS FOR THE ORANGEVILLE RESERVOIR CONTROL STRUCTURE

TOTAL DISCHARGE
CUBIC METRES PER MONTH

MONTH	1980	1981	1982	1983	1984	1985	1986
JANUARY	1288310	757987	401760	1526688	380333	950832	1083974
FEBRUARY	992218	718502	338688	1173312	355795	847584	524966
MARCH	190166	870480	219950	1071360	1847232	776736	581213
APRIL	671328	476928	313632	945821	2348352	1684800	562464
MAY	329443	302659	753667	1134777	2250374	267840	519005
JUNE	821664	220320	834106	733536	438048	259200	458784
JULY	870480	227664	455328	634435	610243	279763	474077
AUGUST	832982	455328	455328	409795	531446	452650	474077
SEPTEMBER	769824	440640	440640	309830	438048	429408	624845
OCTOBER	757987	453280	455328	317001	384220	477792	985651
NOVEMBER	733536	1565568	733536	715910	550800	355104	862618
DECEMBER	757987	1797206	757987	479174	950832	1258848	857088
TOTAL	9015925	8286562	6159950	9451639	11085723	8040557	8008762

TABLE A2.6: CONCENTRATIONS (mg/L) OF CHLORIDE, NITROGEN AND TOTAL PHOSPHORUS IN ORANGEVILLE RESERVOIR WATERSHEDS, 1986

	Monora Creek					East Tributary					North Tributary				
Date	Cl^-	NO_3-N	NO_2-N	TKN	TP	Cl^-	NO_3-N	NO_2-N	TKN	TP	Cl^-	NO_3-N	NO_2-N	TKN	TP
17.01.86	135	1.25	0.014	0.66	0.046	46	2.7	0.018/ 0.018	0.90/ 0.89	0.034	-	-	-	-	-
21.01.86	25	1.01	0.008	0.42	0.018	-	-	-	-	-	-	-	-	-	-
03.02.86	11.3	0.92	0.008	0.44	0.015	-	-	-	-	-	-	-	-	-	-
26.02.86	12.8	1.07	0.006	0.23	0.022/ 0.027	-	-	-	-	-	-	-	-	-	-
05.03.86	16.9	1.01	0.006	0.42	0.021	105	2.7	0.012/ 0.014	0.31	0.022	-	-	-	-	-
11.03.86	23	0.43	0.010	0.86/ 0.80	0.052/ 0.070	21/ 20	1.42/ 1.48	0.012	1.06	0.070/ 0.10	5.3	0.91	0.014	0.93/ 1.03	0.043/ 0.062
12.03.86	15.2	1.19	0.014	0.98	0.082	26	1.36	0.010	0.63	0.074	-	-	-	-	-
18.03.86	13.6/ 13.9	0.82/ 0.82	0.010	0.55/ 0.51	0.032/ 0.042	-	-	-	-	-	4.8	0.91	0.014	0.58	0.018
21.03.86	11.2	0.90	0.010/ 0.010	0.64	0.049/ 0.042	-	-	-	-	-	-	-	-	-	-
26.03.86	10.2	0.61	0.008	0.48/ 0.54	0.056	19.2	0.99	0.010	1.0	0.078	3.8	0.44	0.008/ 0.008	0.41	0.032/ 0.040
03.04.86	12.5	0.62	0.004/ 0.004	0.34	0.012	-	-	-	-	-	-	-	-	-	-
11.04.86	14.0	0.66	0.003	0.31	0.013	42	2.8	0.004	0.37	0.01/ 0.01	-	-	-	-	-
17.04.86	17.5	0.54	0.006	0.42/ 0.44	0.011	35	1.45/ 1.49	0.005/ 0.005	0.59	0.024	7.0	0.36	0.004	0.39	0.016
24.04.86	14.0	0.54	0.003	0.32/ 0.37	0.01	-	-	-	-	-	-	-	-	-	-
01.05.86	13.2	0.62	0.004	0.28	0.017/ 0.017	43	1.10/ 1.14	0.002	0.27	0.029	6.7	0.30	0.006	0.43/ 0.49	0.038
08.05.86	14.0	0.80	0.004	0.37	0.023	-	-	-	-	-	-	-	-	-	-
15.05.86	11.2/ 11.4	0.63/ 0.63	0.004	0.41	0.028	47	1.06/ 1.10	0.004	0.66/ 0.72	0.031	8.6	0.22	0.004/ 0.004	0.71	0.012
20.05.86	13.8	0.38	0.006	0.29	0.020	-	-	-	-	-	-	-	-	-	-
23.05.86	14.0	0.36	0.004/ 0.004	0.41	0.015	44	0.88/ 0.91	0.003	0.65	0.027	-	-	-	-	-
05.06.86	12.6	0.62	0.010	0.55	0.015/ 0.014	46	0.86/ 0.86	0.004	0.58	0.025	7.8/ 7.8	0.18/ 0.18	0.010	0.61	0.012
11.06.86	11.6	0.33	0.007	0.54	0.010	-	-	-	-	-	-	-	-	-	-
20.06.86	11.2	0.58	0.008	0.26/ 0.22	0.016	47	1.01	0.005	0.64	0.018	7.2	0.17	0.006	1.12	0.011
03.07.86	9.8/ 10.4	0.56/ 0.59	0.004	0.35	0.014	4.9	0.89	0.003	0.50	0.016	9.0	0.22	0.006	0.81/ 0.59	0.029
10.07.86	10.2	0.59	0.004	0.42	0.004	-	-	-	-	-	-	-	-	-	-
11.07.86	10.0	0.65	0.003	0.28	0.012	-	-	-	-	-	-	-	-	-	-
17.07.86	12.5	0.41	L 0.001	1.14	0.032	45	0.46/ 0.42	L 0.001	1.23	0.054	11.7	0.23	0.012	0.88	0.03
24.07.86	9.9	0.49	0.006	0.41	0.018	41	0.84	0.006/ 0.007	0.63	0.017/ 0.024	9.1	0.10	0.003	0.66	0.015
30.07.86	9.6	0.45	0.004	0.32/ 0.20	0.010	42	0.84	0.006	0.27	0.052	9.5	0.28	0.003	0.39	0.060
06.08.86	9.5	0.83	0.008	0.085	0.016	-	-	-	-	-	-	-	-	-	-
14.08.86	10.4	0.46	0.005	1.54	0.022/ 0.030	50	0.95/ 1.02	0.004	0.67	0.059/ 0.057	9.3	0.24	0.005	0.94	0.054
20.08.86	11.9	0.65	0.022	0.39	0.009	-	-	-	-	-	-	-	-	-	-
28.08.86	12.8	0.45	0.015	0.64	0.050	-	-	-	-	-	-	-	-	-	-
11.09.86	7.5	0.16	0.009	1.57	0.073	26.3	0.40	0.006	1.26	0.086	7.2	0.20	0.004	0.69	0.056/ 0.056
30.09.86	11.0	0.20	0.004	0.41	0.024	-	-	-	-	-	-	-	-	-	-
09.10.86	13.2	0.46	0.004/ 0.005	0.30	0.013	-	-	-	-	-	-	-	-	-	-
24.10.86	12.3	0.32	0.002	0.20	0.008	51.0	1.1/ 1.16	0.004	0.52	0.016	18.1	0.24	0.003	0.95	0.015
07.11.86	11.3	0.69	0.001	0.30	0.023	-	-	-	-	-	-	-	-	-	-
21.11.86	11.0	1.1	0.002	0.29	0.005	-	-	-	-	-	-	-	-	-	-
05.12.86	14.0	0.84	0.007	0.23	0.007	28.0	2.4	0.037	0.50	0.007	6.3	0.91	0.016	0.88/ 0.64	0.014

TABLE A2.7: STREAM FLOW, WATER QUALITY AND LOADINGS OF CHLORIDE, NITROGEN AND PHOSPHORUS IN MONORA CREEK, 1986

Period	Interval Volume (m^3)	Mean Concentration (mg/L)					Loading (kg)					
		Cl^-	NO_3-N	NO_2-N	TKN	TP	Cl^-	NO_3-N	NO_2-N	TKN	TN	TP
01.01-19.01	193,750	135	1.25	0.014	0.66	0.046	26,156	242	2.7	13	259	8.9
19.01-25.01	132,450	25	1.01	0.008	0.42	0.018	3,311	134	1.1	56	190	2.4
25.01-12.02	143,310	11.3	0.92	0.008	0.44	0.015	1,619	132	1.2	63	196	2.2
12.02-01.03	78,600	12.8	1.07	0.006	0.23	0.0245	1,006	84.1	0.5	18	149	1.93
01.03-07.03	25,800	16.9	1.01	0.006	0.42	0.021	436	26.1	0.2	11	37	0.54
07.03-11.03	96,200	23	0.43	0.010	0.83	0.061	2,212	41.37	0.96	80	217	5.9
11.03-14.03	133,700	15.2	1.19	0.014	0.98	0.082	2,032	159	1.9	131	292	11
14.03-18.03	170,500	13.75	0.82	0.010	0.53	0.037	2,344	140	1.7	90	232	6.3
18.03-23.03	236,000	11.2	0.90	0.010	0.64	0.0455	2,643	212	2.4	151	366	10.7
23.03-30.03	190,000	10.2	0.61	0.008	0.51	0.056	1,938	116	1.5	97	214	11
30.03-07.04	206,500	12.5	0.62	0.004	0.34	0.012	2,581	128	0.8	70	199	2.5
07.04-15.04	188,000	14.0	0.66	0.003	0.31	0.013	2,632	124	0.6	58	183	2.4
15.04-19.04	106,000	17.5	0.54	0.006	0.43	0.011	1,855	57	0.6	46	103	1.2
19.04-28.04	169,666.6	14.0	0.54	0.003	0.345	0.01	2,375	92	0.5	58.5	151	1.7
28.04-02.05	63,666.7	13.2	0.62	0.004	0.28	0.017	840	39	0.3	18	58	1.1
02.05-12.05	114,999.9	14.0	0.80	0.004	0.37	0.023	1,609	92	0.5	43	135	2.6
12.05-17.05	51,333.4	11.3	0.63	0.004	0.41	0.028	580	32	0.2	21	54	1.4
17.05-21.05	101,333.3	13.8	0.38	0.006	0.29	0.020	1,398	39	0.6	29	69	2.0
21.05-28.05	50,000	14.0	0.36	0.004	0.41	0.015	700	18	0.2	21	39	0.75
28.05-08.06	86,000	12.6	0.62	0.010	0.55	0.0145	1,083	53	0.86	47	101	1.25
08.06-18.06	36,000	11.6	0.33	0.007	0.54	0.010	417	12	0.3	19	32	0.36
18.06-25.06	90,800	11.2	0.58	0.008	0.24	0.016	1,016	53	0.7	22	75	1.45
25.06-08.07	88,200	10.1	0.575	0.004	0.35	0.014	890	50.7	0.4	31	82	1.23
08.07-10.07	7,300	10.2	0.59	0.004	0.42	0.004	74	4.3	0.03	3.1	7	0.03
10.07-14.07	34,133.3	10.0	0.65	0.003	0.28	0.012	341	22	0.1	9.6	32	0.41
14.07-20.07	26,833.4	12.5	0.41	L 0.001	1.14	0.032	335	11	L 0.03*	30.6	42	0.86
20.07-28.07	56,433.3	9.9	0.49	0.006	0.41	0.018	558	28	0.3	23	51	1.0
28.07-02.08	29,600	9.6	0.45	0.004	0.26	0.010	2,842	13	0.1	7.7	21	0.29
02.03-09.08	46,200	9.5	0.83	0.008	0.085	0.016	438	38	0.4	3.9	43	0.74
09.08-17.08	144,533.4	10.4	0.46	0.005	1.54	0.025	1,503	66	0.7	223	290	3.6
17.08-24.08	98,333.3	11.9	0.65	0.022	0.39	0.009	1,170	64	2.2	38	104	38
24.08-04.09	198,333.3	12.8	0.45	0.015	0.64	0.050	2,538	89	2.97	127	219	9.9
04.09-18.09	706,500	7.5	0.16	0.009	1.57	0.073	5,298	113	6.4	1,110	1,229	51.6
18.09-02.10	274,000	11.0	0.20	0.004	0.41	0.024	3,014	55	1	112	168	6.6
02.10-17.10	468,000	13.2	0.46	0.0045	0.30	0.013	6,177	215	2.1	140	358	6.1
17.10-01.11	355,000	12.3	0.32	0.002	0.20	0.008	4,366	114	0.7	71	185	3
01.11-14.11	288,500	11.3	0.69	0.001	0.30	0.023	3,260	199	0.3	87	286	6.6
14.11-28.11	220,000	11.0	1.1	0.002	0.29	0.005	2,420	242	0.4	64	306	1
28.11-31.12	390,500	14.0	0.84	0.007	0.23	0.007	5,467	328	2.7	90	421	3
TOTALS	6.098×10^6						101,500	3,600	41	3,300	7,200	220

* Assumed to be at the detection limit for loadings calculations.

TABLE A2.8: STREAM FLOW, WATER QUALITY AND LOADINGS OF CHLORIDE, NITROGEN AND PHOSPHORUS IN THE EAST TRIBUTARY, 1986

Period	Interval Volume (m^3)	Mean Concentration (mg/L)					Loading (kg)					
		Cl^-	NO_3-N	NO_2-N	TKN	TP	Cl^-	NO_3-N	NO_2-N	TKN	TN	TP
01.01-12.02	58,018	46	2.7	0.018	0.875	0.034	2,700	160	1.04	50.8	209	1.97
12.02-09.03	14,019	105	2.7	0.013	0.31	0.022	1,470	38	0.18	4.3	42	0.31
09.03-11.03	20,859	20.5	1.45	0.012	1.06	0.085	428	30.2	0.25	22.1	53	1.77
11.03-18.03	34,169	26	1.36	0.010	0.63	0.074	890	46.5	0.34	22	68	2.5
18.03-03.04	67,089	19.2	0.99	0.010	1.0	0.078	1,290	66	0.67	67	134	5.2
03.04-14.04	28,641.5	42	2.8	0.004	0.37	0.01	1,200	80	0.11	11	91	0.29
14.04-24.04	29,980.5	35	1.47	0.005	0.59	0.024	1,050	44.1	0.15	18	62	0.72
24.04-08.05	31,449	43	1.12	0.002	0.27	0.029	1,350	35.2	0.06	8.5	44	0.91
08.05-17.05	15,466	47	1.08	0.004	0.69	0.031	730	16.7	0.06	11	27	0.48
17.05-01.06	32,141	44	0.895	0.003	0.65	0.027	1,400	28.8	0.09	21	50	0.87
01.06-11.06	23,328	46	0.86	0.004	0.58	0.025	1,070	20	0.09	14	34	0.58
11.06-30.06	33,696	47	1.01	0.005	0.64	0.018	1,580	34.0	0.02	22	56	0.61
30.06-10.07	27,043	49	0.89	0.003	0.50	0.016	1,330	24	0.08	14	38	0.43
10.07-20.07	26,006	45	0.44	L 0.001*	1.23	0.054	1,170	11	0.03	31.9	43	1.40
20.07-27.07	15,033.5	41	0.84	0.0065	0.63	0.0205	616	13	0.09	9.5	22	0.31
27.07-06.08	18,662.5	42	0.84	0.006	0.27	0.052	780	16	0.01	5.0	21	0.97
06.08-28.08	53,740	50	0.985	0.004	0.67	0.058	2,690	52.9	0.21	36	89	3.12
28.08-09.10	195,863	26.3	0.40	0.006	1.26	0.086	5,150	78	1.18	247	326	16.8
09.10-14.11	176,170	51.0	1.13	0.004	0.52	0.016	8,990	199.0	0.70	92	291	2.8
14.11-31.12	138,382	28.0	2.4	0.037	0.50	0.007	3,870	332	5.1	69	406	0.97
TOTALS	1.040×10^6						39,800	1,320	10	772	2,100	43

* Assumed to be at the detection limit for loadings calculations.

TABLE A2.9: STREAM FLOW, WATER QUALITY AND LOADINGS OF CHLORIDE, NITROGEN AND PHOSPHORUS FROM THE NORTH TRIBUTARY, 1986

Period	Interval Volume (m^3)	Mean Concentration (mg/L)					Loadings (kg)					
		Cl^-	NO_3-N	NO_2-N	TKN	TP	Cl^-	NO_3-N	NO_2-N	TKN	TN	TP
01.01-05.03	5,500	5.3	0.91	0.014	0.98	0.053	29	5.01	0.08	5.4	10.5	0.29
05.03-11.03	20,000	5.3	0.91	0.014	0.98	0.053	106	18.2	0.28	19.6	38.1	1.06
11.03-21.03	49,000	4.8	0.91	0.014	0.58	0.018	235	44.6	0.69	28.4	73.7	0.88
21.03-03.04	41,000	3.8	0.44	0.008	0.41	0.036	156	18.0	0.33	16.8	35.0	1.48
03.04-24.04	52,000	7.0	0.36	0.004	0.39	0.016	364	18.7	0.21	20.3	39.2	0.83
24.04-08.05	28,000	6.7	0.30	0.006	0.46	0.038	188	8.4	0.17	12.9	21.5	1.06
08.05-20.05	18,000	8.6	0.22	0.004	0.71	0.012	155	4.0	0.07	12.8	16.9	0.22
20.05-11.06	45,000	7.8	0.18	0.010	0.61	0.012	351	8.1	0.45	27.5	36.1	0.54
11.06-25.06	27,000	7.2	0.17	0.006	1.12	0.011	243	4.6	0.16	30.2	35.0	0.30
25.06-10.07	29,000	9.0	0.22	0.006	0.70	0.029	261	6.4	0.17	20.3	26.9	0.84
10.07-20.07	19,000	11.7	0.23	0.012	0.88	0.03	222	4.4	0.23	16.7	21.3	0.57
20.07-27.07	13,000	9.1	0.10	0.003	0.66	0.015	118	1.3	0.04	8.6	9.9	0.20
27.07-06.08	17,000	9.5	0.28	0.003	0.39	0.060	162	4.8	0.05	6.6	11.5	1.02
06.08-28.08	48,000	9.3	0.24	0.005	0.94	0.054	446	11.5	0.24	45.1	56.8	2.59
28.08-25.09	100,000	7.2	0.20	0.004	0.69	0.056	720	20.0	0.40	69.0	89.4	5.60
25.09-07.11	210,000	18.1	0.24	0.003	0.95	0.014	3,800	50.4	0.63	200	251	2.94
07.11-31.12	140,000	6.3	0.91	0.016	0.76	0.014	882	127	2.2	106	235	1.96
TOTAL	8.6×10^5						8,440	355	6.4	646	1,008	22.4

TABLE A2.10: DISCHARGE, WATER QUALITY AND LOADINGS OF CHLORIDE, NITROGEN AND PHOSPHORUS AT THE SOUTH DYKE CONTROL STRUCTURE, 1986

Period	Interval Volume (m^3)	Mean Concentration (mg/L)					Loadings (kg)					
		Cl^-	NO_3-N	NO_2-N	TKN	TP	Cl^-	NO_3-N	NO_2-N	TKN	TN	TP
January	1,083,974	16.17	0.2568	0.0098	0.397	0.012	17,528	278	10.7	430	719	13.0
February	524,966	24.30	0.2607	0.0060	0.450	0.016	12,757	137	3.1	236	376	8.4
March	581,213	28.53	0.4893	0.0090	0.543	0.039	16,582	284	5.2	316	605	22.9
April	562,464	16.50	0.0883	0.0068	0.440	0.027	9,281	49.6	3.8	247	301	14.9
May	519,005	15.33	0.0363	0.0053	0.513	0.023	7,956	18.9	2.8	266	288	12.1
June	458,784	17.50	0.0760	0.0073	0.567	0.018	8,029	34.9	3.4	260	298	8.1
July	474,077	15.60	0.0553	0.0077	0.536	0.026	7,396	26.2	3.7	254	284	12.1
August	474,077	14.63	0.0314	0.0024	0.528	0.022	6,936	14.9	1.1	250	266	10.2
September	624,845	14.20	0.0312	0.0048	0.492	0.015	8,873	19.5	3.0	307	330	9.4
October	985,651	14.00	0.0203	0.0047	0.403	0.010	13,799	20.0	4.6	398	422	9.5
November	862,618	21.17	0.4974	0.0048	0.480	0.014	18,262	429	4.2	414	847	12.4
December	857,088	18.96	0.1168	0.0032	0.430	0.030	16,250	100	2.7	369	471	25.5
TOTAL	8,008,762						143,648	1,412	48.3	3,747	5,207	158.5

TABLE A2.11: NUTRIENT CONTENTS OF SURFICIAL SEDIMENTS FROM THE ORANGEVILLE RESERVOIR

Sample No.	Nutrient Concentration (% dry weight)	
	TKN	TP
1985		
1	1.76	0.08
2	1.93	0.23
3	0.8	0.07
4	1.72	0.12
1986		
1 (Station 2)	3.9	0.162
2	2.8	0.172
3	3.9	0.172
Mean Concentrations	2.4	0.14

TABLE A2.12: NUTRIENT CONTENT OF SEDIMENT POREWATERS, SURFACE WATER COMPOSITES AND BOTTOM* WATER SAMPLES FROM THE ORANGEVILLE RESERVOIR, 1986

Sample Type/Date		Concentration (mg/L) NO_3-N	NO_2-N	TKN	TP	D.O.**	Temp (^oC)
Porewater	(25 Jun)	0.77	0.015	0.15	2.4		
	(05 Aug)	0.01	0.019	8.9	1.0		
	(28 Aug)	0.25	0.021	15.4	0.09		
Station 1:	Composite (25 Jun)	LT 0.01	LT 0.001	0.28	0.015	8.7	18.1
	Bottom	LT 0.01	LT 0.001	0.30	0.014	4.4	18.0
	Composite (07 Aug)	LT 0.01	LT 0.001	0.34	0.0135	9.6	21.8
	Bottom	LT 0.01	LT 0.001	0.12	0.009	2.1	21.5
	Composite (28 Aug)	LT 0.01	0.001	0.58	0.033	9.9	16.5
	Bottom	-	-	-	-	9.8	16.5
Station 2:	Composite (25 Jun)	LT 0.01	0.001	0.36	0.015	9.6	19.8
	Bottom	LT 0.01	0.001	0.30	0.026	2.6	16.9
	Composite (07 Aug)	LT 0.01	LT 0.001	0.53	0.007	8.1	22.0
	Bottom	0.01	0.0185	8.9	1.0	0.4	20.0
	Composite (28 Aug)	LT 0.01	0.002	0.57	0.020	8.6	18
	Bottom	-	-	-	-	7.7	17

* Bottom water samples from 0.5 to 1 m above bottom.

** Dissolved oxygen and temperature readings for "composite" samples taken at 0.5 m below the surface.

TABLE A2.13: NUTRIENT CONCENTRATIONS (PERCENT DRY WEIGHT) IN PLANTS HARVESTED FROM THE ORANGEVILLE RESERVOIR IN 1986

Sample No.[1]	Nutrient Concentration	
	TKN	TP
1-2-3	1.56	0.17
4-5-6	1.68	0.32
7-8-9	1.50	0.26
Means	1.58	0.25

[1] 1-2-3 - plants harvested June-early July.
4-5-6 - plants harvested early-late July.
7-8-9 - plants harvested August.